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USAAMRDL TECHNICAL REPORT 71-41B

SURVIVABILITY DESIGN GUIDE FOR U. S. ARMY AIRCRAFT (U)

VOLUME II

CLASSIFIED DATA FOR SMALL-ARMS BALLISTIC PROTECTION (U)

By

Walter D. Dotseth

November 1971

FEB 1972

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

CONTRACT DAAJ02-70-C-0044
LOS ANGELES DIVISION OF NORTH AMERICAN ROCKWELL
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(U) ERRATA

USAAMRDL Technical Report 71-41B
TITLE: Survivability Design Guide for U. S. Army Aircraft (U)
Volume II - Classified Data for Small-Arms Ballistic Protection (U)

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Make the following changes:

Page	
vii	Change the page number for List of Illustrations from vii to viii
vii	Change the page number for List of Tables from vii to x
50, para 4.1	Change USAAMRDC to USAAMRDL

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(U) This first edition of Small-Arms Ballistic Protection Survivability Design Guide for U.S. Army Aircraft was prepared by North American Rockwell, Los Angeles Division, under the terms of Contract DAAJ02-70-C-0044.

(U) Under the contract, Army aircraft survivability design data generated over the past ten years were compiled and analyzed in the area of aircraft vulnerability reduction and aircrew protection against small-arms fire. From this source of information, pertinent design data related to aircraft vulnerability reduction and aircrew protection were selected and developed into this design guide for use by aircraft engineers, designers, and other personnel responsible for Army aircraft survivability.

(U) The contents of this guide have been coordinated with the Air Force Flight Dynamics Laboratory, Army Ballistic Research Laboratories, and the Army Materials and Mechanics Research Center. It is expected that revisions will be made and published from time to time to correct and update the guide and to add pertinent information as it becomes available.

(U) Comments or suggestions pertaining to the data contained in this guide will be welcomed by this Directorate.

(U) The technical monitor for this contract was Mr. Stephen Pociluyko, Safety and Survivability Division.

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VOLUME II. - CLASSIFIED DATA FOR SMALL-ARMS
BALLISTIC PROTECTION (U).

(9) Technical rept.

by

(10) Walter D. Dotseth

Prepared by

Los Angeles Division of North American Rockwell

for

EUSTIS DIRECTORATE

U.S. ARMY AIR MOBILITY RESEARCH AND
DEVELOPMENT LABORATORY

FORT EUSTIS, VIRGINIA

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(U) ABSTRACT

(U) An extensive literature and information search was conducted to identify military aircraft small-arms protection enhancement techniques developed during the past 10 years. This data was analyzed and used to develop a comprehensive survivability design guide for incorporation of ballistic protection features in U.S. Army aircraft. This document contains classified information that supplements the information contained in the unclassified Volume 1 (USAAMRDL Technical Report 71-41A).

(U) FOREWORD

(U) This document was prepared for the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, by the Los Angeles Division of North American Rockwell Corporation, under Contract DAAJ02-70-C-0044 (Task 1F162203A15003). The data contained in this publication was obtained through an extensive search of related published documents and other data developed during the past 10 years. This document contains classified information that supplements the unclassified data and guidance contained in Volume I.

(U) TABLE OF CONTENTS

(U) LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONT)

(U) LIST OF TABLES

(U) INTRODUCTION

(U) This document contains classified information that is to be used in conjunction with the unclassified Volume I "Small-Arms Ballistic Protection" of USAAMRDL Technical Report 71-41A "Survivability Design Guide for U.S. Army Aircraft". Together, these documents comprise the latest information and guidance to be used for design and incorporation of small-arms ballistic protection feature in U.S. Army aircraft. The information includes methodology for prediction of single-shot kill probabilities, hostile small-arms threat data, armor material characteristics, and projectile slow down through liquids information.

CHAPTER I

(C) SINGLE-ENGAGEMENT KILL PROBABILITY (U)

1.1 (U) INTRODUCTION

(U) The data presented herein is to supplement that contained in paragraph 1.3 of Volume I (USAAMRDL Technical Report 71-41A). It is a methodology for determining single-engagement kill probabilities of burst-fired small-arms and air defense gun systems. This expression, called the salvo fire equation, assumes complete "dependence" or correlation between rounds fired in a burst.

1.2 (C) SINGLE-ENGAGEMENT KILL PROBABILITY BY CONTACT ROUNDS (U)

(C) Assuming target detection, projectile firing, or launch, and assuming that all components of the hostile system have functioned as designed so as to deliver the projectile to the vicinity of the target, the single-engagement kill probability (P_K) is determined as follows. For burst-fire weapons, the probability of kill within a burst is given by:

$$P_{K/Bi} = \left[\sum_{j=1}^{N_{Bi}} \binom{N_{Bi}}{j} \left(-1\right)^{j+1} \left(\frac{A_{V_i}}{2\pi\sigma_{R_i}^{2} + A_{V_i}} \right)^{j-1} \left(\frac{A_{V_i}}{2\pi\left(\sigma_{R_i}^{2} + j\sigma_{S_i}^{2}\right) + A_{V_i}} \right) \cdot e^{-\left(\frac{j\pi h_i^{2}}{2\pi(\sigma_{R_i}^{2} + j\sigma_{S_i}^{2}) + A_{V_i}} \right)} \right]$$

This is the dependent or salvo fire form of the equation for attrition for a single burst. The probability of kill for the entire engagement is given by:

$$P_{K/E} = 1 - \prod_{i=1}^{K} (1 - P_{K/Bi})$$

where j equals the round number and i is the burst number in a series of K-bursts.

A_V = The total target vulnerable area seen by the weapon (square meters)

σ_{Si} = Bias errors (standard deviation, meters)

σ_{Ri} = Dispersion errors (standard deviation, meters)

N_B = Number of rounds fired in a burst

h = Error due to target maneuver (zero if no evasive target maneuvers are employed), and $\binom{N_B}{j} = \frac{N_B!}{j!(N_B-j)!}$

The levels of kill must be considered in the analysis. For rotary-wing aircraft, they are attrition (ATT), forced landing (FL), and mission abort (MA). For fixed-wing aircraft, they are "KK," "K," "A," "B," "C," and "E."

a. (U) Attrition level kill for a rotary-wing aircraft would be:

$$P_{K_{ATT}} = 1 - (1 - P_{K_{ATTSV}}) (1 - P_{K_{NP}} \cdot P_{K_{FP}})$$

where $P_{K_{ATTS}}$ represents the probability of kill for single vulnerable components, and $P_{K_{NP}}$ and $P_{K_{FP}}$ are the probabilities of kill for the near pilot and far pilot (or copilot), respectively. These last represent multiple vulnerable components.

b. (U) Forced landing kill probability for a single engine, single pilot aircraft takes into consideration only single vulnerable components are:

$$P_{K_{FL}} = P_{K_{FLSV}}$$

where $P_{K_{FLSV}}$ represents the probability of forced landing for single vulnerable components.

c. (U) Forced landing kill probability of a twin engine, single pilot aircraft must consider both single and multiple vulnerable components as follows:

$$P_{K_{FL}} = 1 - (1 - P_{K_{FLSV}}) (1 - P_{K_{NE}} \cdot P_{K_{FE}})$$

where $P_{K_{FLNE}}$ and $P_{K_{FLFE}}$ are the probabilities of forced landing kill for the near engine and far engine, respectively. (C)

1.3 (C) SMALL-ARMS AND 23 MM/57-MM OPTICAL SYSTEMS (U)

(C) The Military Potential Test (MPT) equations for optically directed systems are as follows:

$$\sigma_T = \sqrt{\sigma_B^2 + \sigma_D^2}$$

$$\sigma_B \text{ (mils)} = 8.75 + 130\,\dot{\theta}^2$$

$$\sigma_B \text{ (meters)} = \sigma_B \text{ (mils)} \cdot \frac{R}{1018.59}$$

$$\sigma_D \text{ (mils)} = 5.287 + 11.4\,\dot{\theta} + 53\,\dot{\theta}^2$$

$$\sigma_D \text{ (meters)} = \sigma_D \text{ (mils)} \cdot \frac{R}{1018.59}$$

$$\dot{\theta} = V_T \cdot \frac{R_m}{R^2}$$

For 14.5-mm and 23-mm, and 57-mm optically directed systems, $\sigma_D = 0.274\ V_T$.

$\dot{\theta}$ = Angular rate of the line-of-sight between the weapon and the target (radians per second)

V_T = Target velocity (meters per second)

R_m = Slant range to target at crossover (meters)

R = Slant range to target (meters)

σ_B = Bias errors (standard deviation)

σ_D = Dispersion errors (standard deviation)

σ_T = Total gun system errors (standard deviation) if dispersion errors are assumed to be independent and randomly distributed about the target

CHAPTER 2

(C) SMALL ARMS WEAPONS CHARACTERISTICS (U)

2.1 (U) INTRODUCTION

(U) This section contains classified data on small-arms weapons that supplements the unclassified information contained in Section 2 of Volume I (USAAMRDL Technical Report 71-41A).

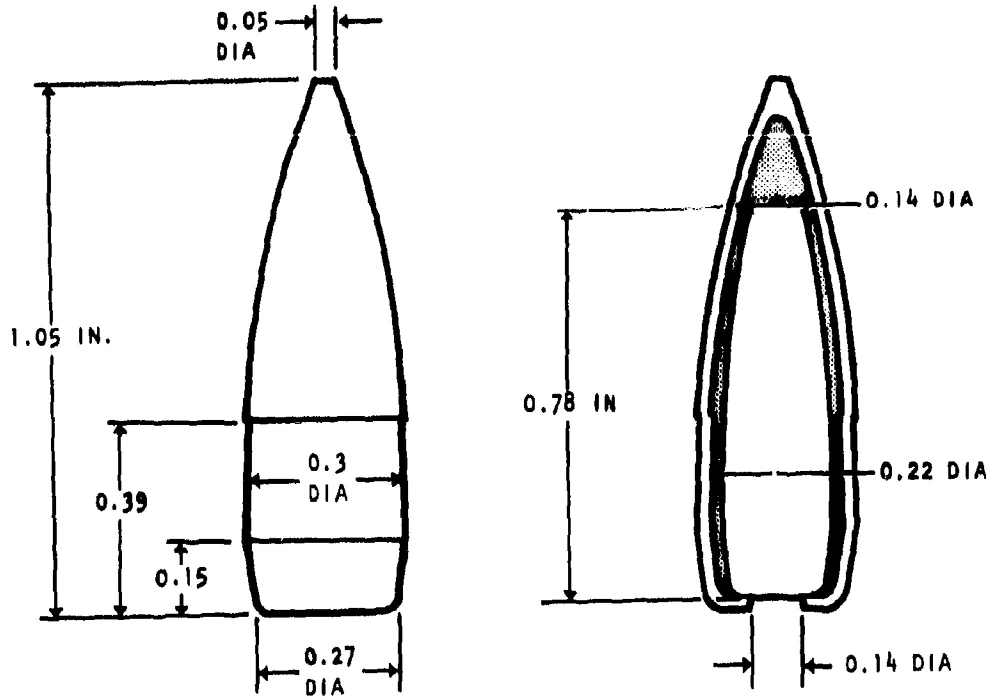
(U) Table I shows the current distribution of representative small-arms weapons (12.7-mm and 14.5-mm) and the 23-mm weapons in Communist Bloc countries. Figures 1 through 9 provide available data on ball and armor-piercing projectiles. This type information is used in predicting the response of materials to ballistic impact.

(U) Tables II through IX provide data on the penetration capabilities of a representative range of small-arms projectiles for homogeneous steel and aluminum armor at various ranges. Table X provides characteristics and performance data on Soviet 14.5-mm antiaircraft machineguns.

(U) Figures 10 through 15 show the altitude and range capabilities of representative small-arms weapons for a range of elevation firing angles. This information is useful in evaluating the capabilities of hostile weapons against aircraft at various altitudes and offset ranges.

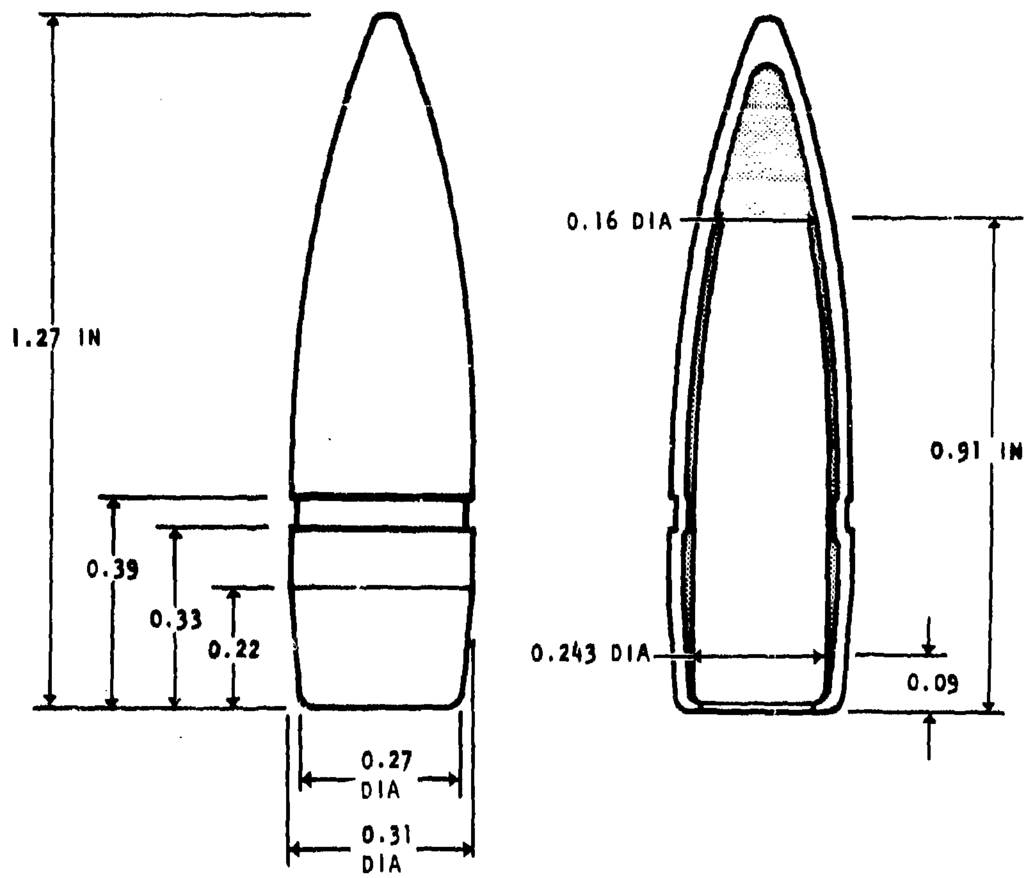
TABLE I. (C) COMMUNIST WEAPON PROLIFERATION (U)

Country \ Weapon	12.7-mm M38/46	Czech QUAD 12.7-mm MG	14.5-mm AA MG ZPU-1	14.5-mm ZPU-2	14.5-mm ZPU-4	23-mm ZU-23	23-mm ZSU-23-4
USSR	X			X	X	X	X
Other Warsaw Pact	X	X		X	X	X	X
CHICOM	X			X	X		
Cuba	X	X			X		
NVN	X		X	X	X	X	
Viet Cong	X						
Laos	X		X	X	X	X	
North Korea	X			X	X		
Afghanistan	X	X					
Syria	X		X	X	X		
UAR	X	X	X	X	X		
Indonesia	X	X					
Iraq	X						
Algeria	X			X	X		
Cambodia	X			X			
Guinea	X	X					
Ghana	X					X	
Somali	X				X		
Cyprus	X			X			
Yemen	X						
Albania	X						



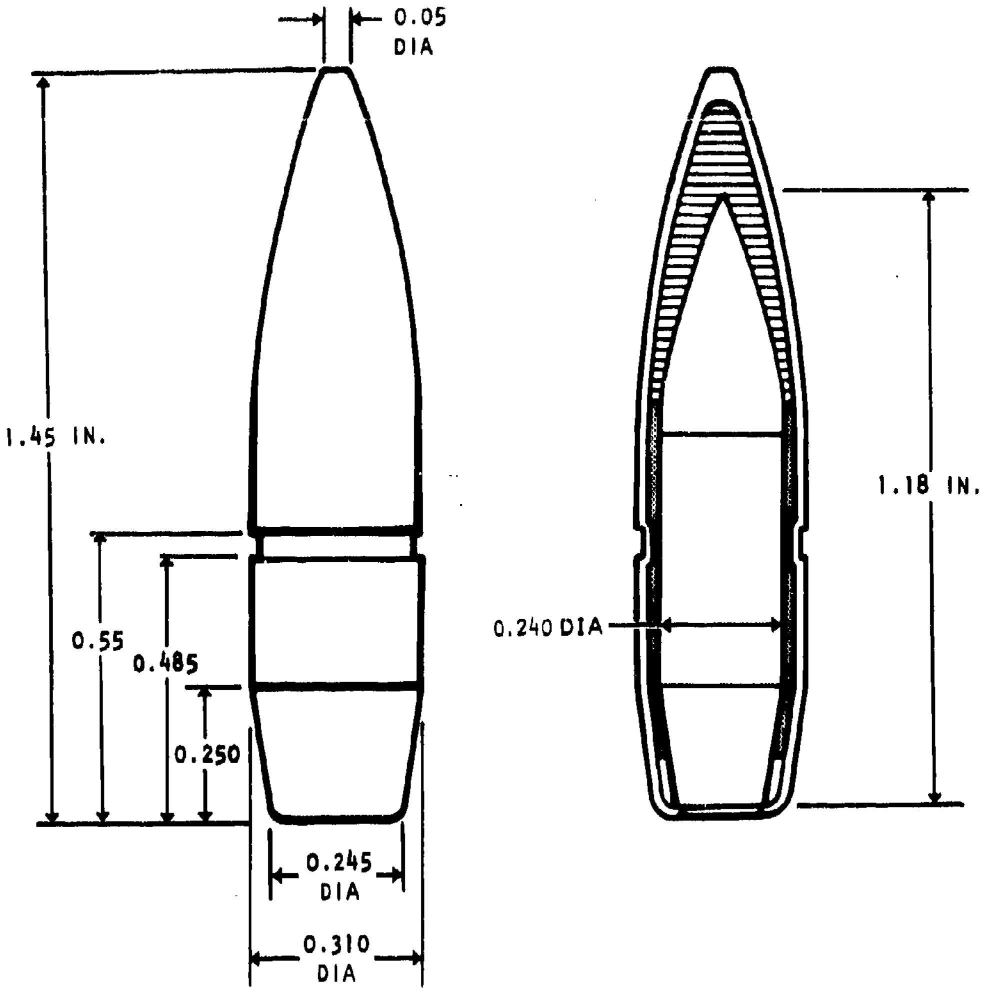
BULLET PART	MATERIAL	WEIGHT (GR)
JACKET	LOW CARBON STEEL, GILDING-METAL CLAD	34
CORE	LOW CARBON STEEL	55
FILLER	LEAD	33

Figure 1. (C) 7.62-mm Ball Bullet Type Physical Dimensions (U).



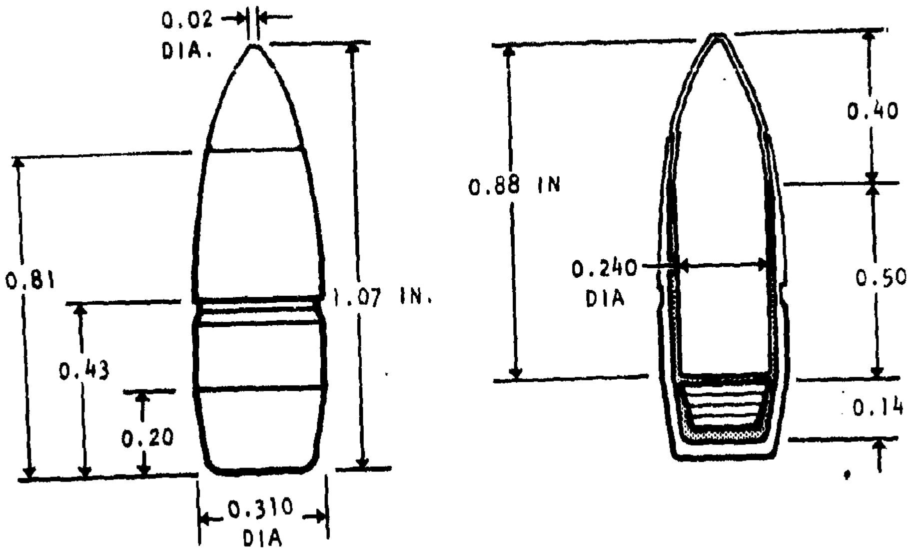
BULLET PART	MATERIAL	WEIGHT (GR)
JACKET	LOW CARBON STEEL, GILDING-METAL CLAD	39
FILLER	LEAD	36
CORE	LOW CARBON STEEL	73

Figure 2. (C) 7.62-mm Ball Bullet Type LPS (U).



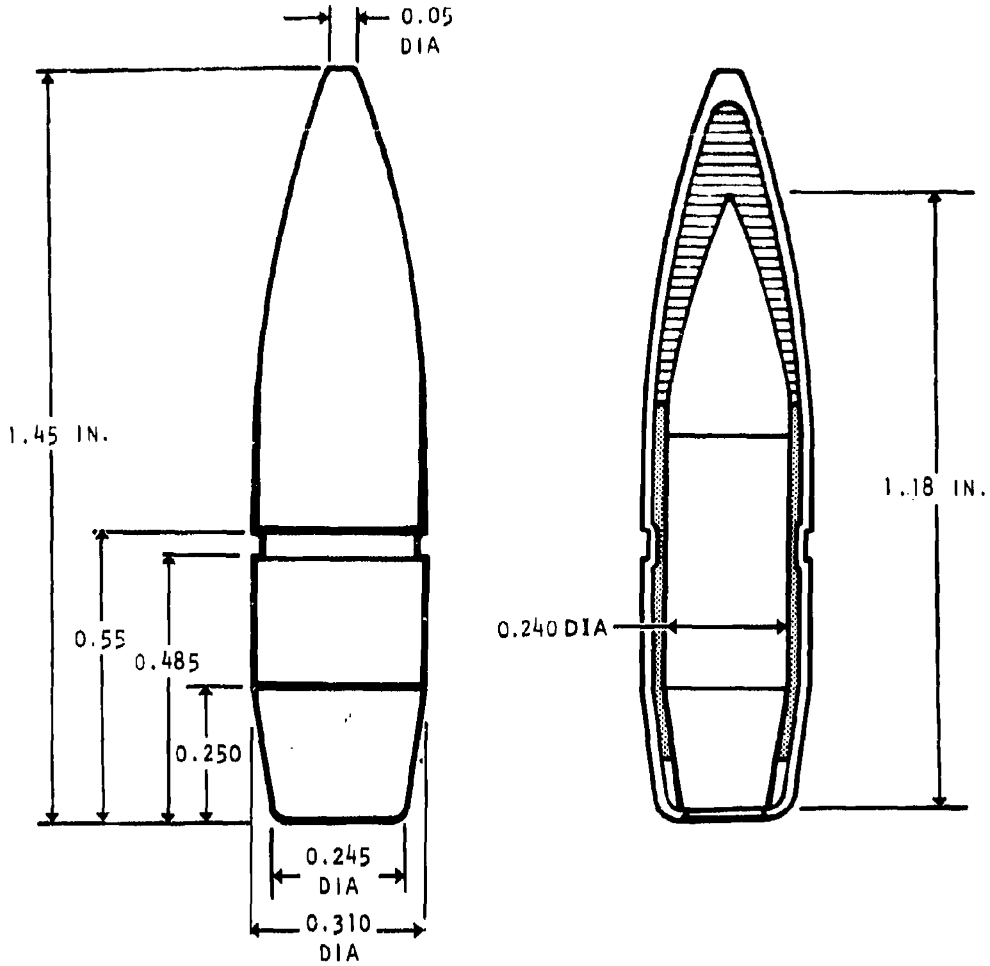
BULLET	MATERIAL	WEIGHT (GR)
JACKET	LOW CARBON STEEL, GILDING-METAL CLAD	31
CORE	LEAD	117

Figure 3. (C) 7.62-mm Ball Bullet Type L (U).



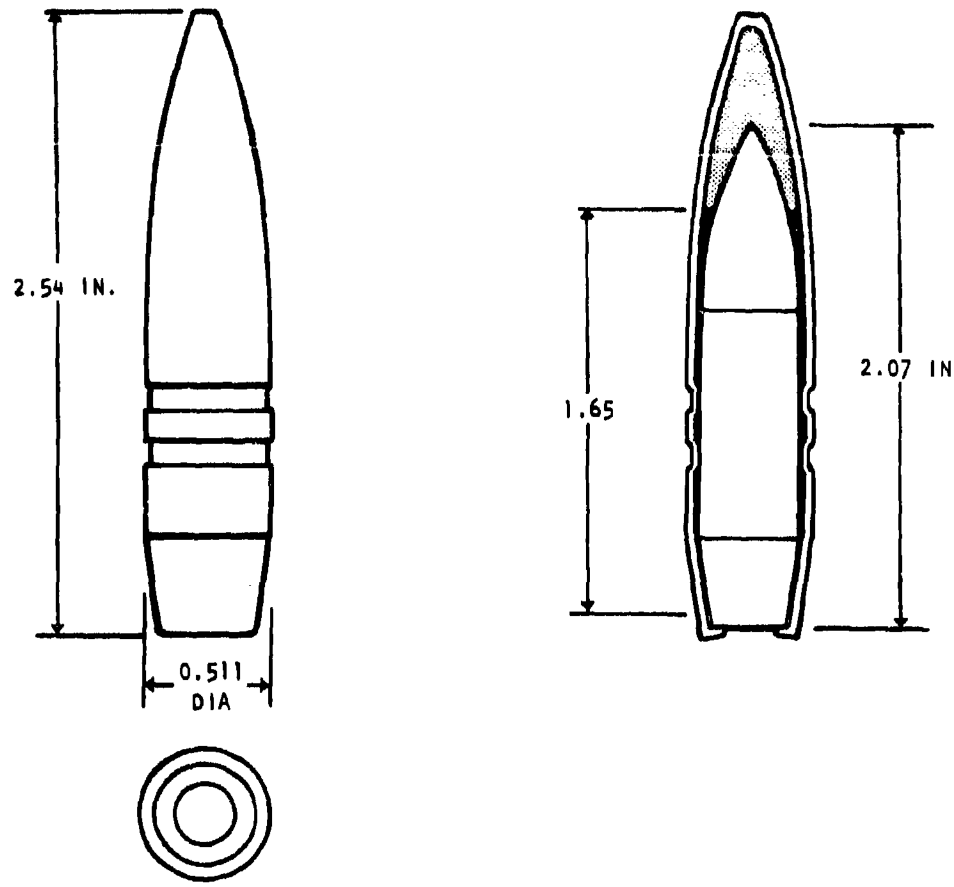
BULLET PART	MATERIAL	WEIGHT (GR)
JACKET (NOSE)	GILDING METAL	4
JACKET (BASE)	LOW CARBON STEEL, GILDING-METAL CLAD	26
CORE	HIGH CARBON STEEL	62
FILLER	LEAD	17
INCENDIARY	MAGNESIUM, ALUMINUM, AND BARIUM NITRATE	2
CUP	LEAD	8

Figure 4. (C) 7.62-mm API Bullet Type BZ (U).



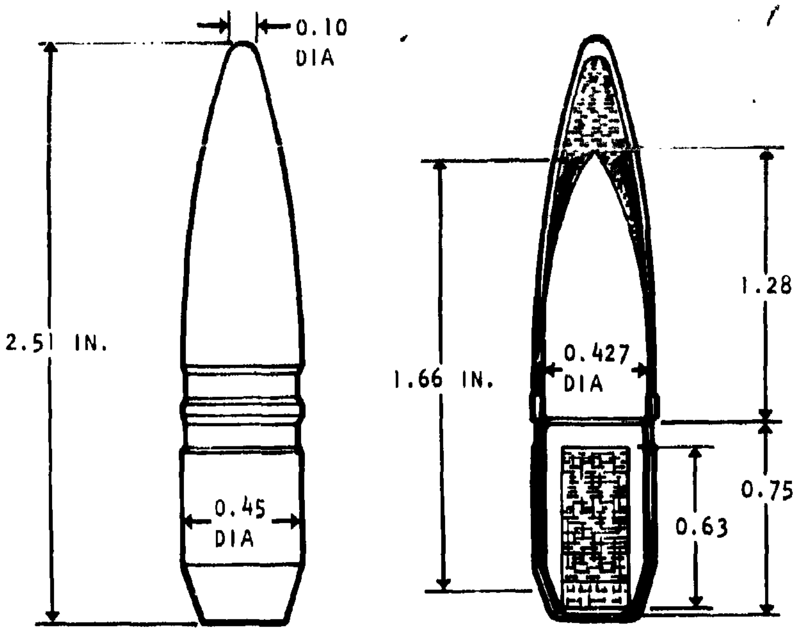
BULLET PART	MATERIAL	WEIGHT (GR)
JACKET	LOW CARBON STEEL, GILDING-METAL CLAD	48
CORE	HIGH CARBON STEEL	83
SHEATH	LEAD	20
INCENDIARY	ALUMINUM, MAGNESIUM, AND BARIUM NITRATE	4

Figure 5. (C) 7.62-mm API Bullet Type B-32 (U).



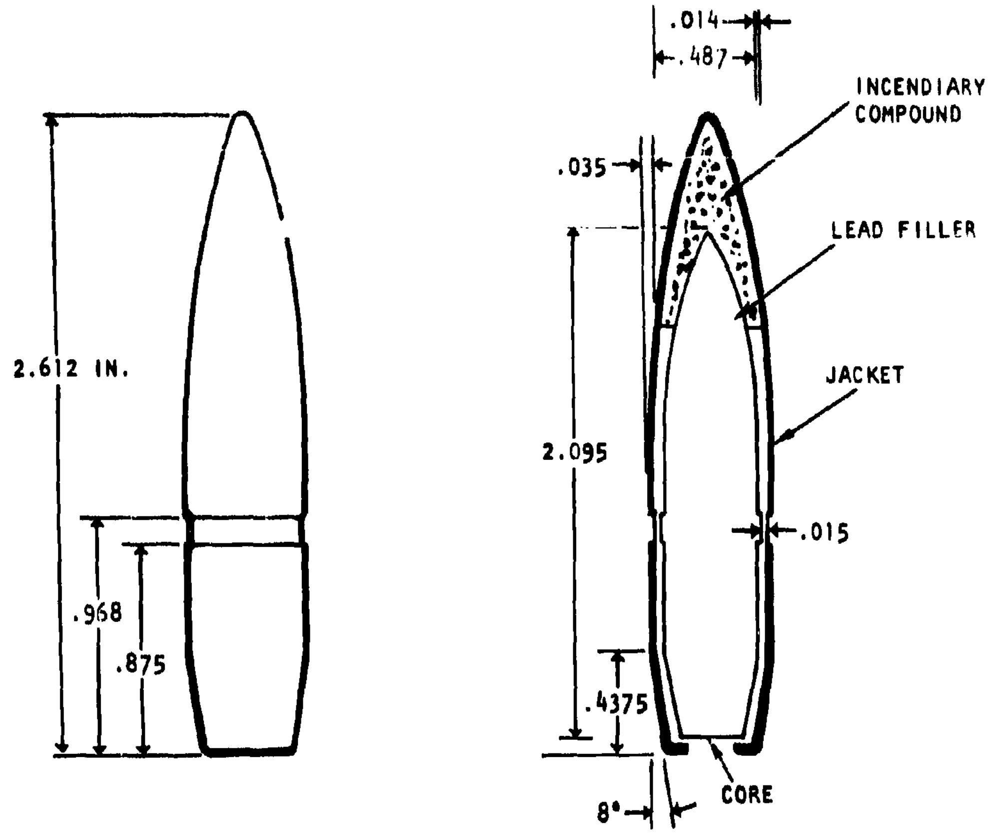
BULLET PART	MATERIAL	WEIGHT (GR)
JACKET	LOW CARBON STEEL, GILDING-METAL CLAD	177
SLEEVE	LEAD	89
CORE	HIGH CARBON STEEL	463
INCENDIARY	ALUMINUM, MAGNESIUM, AND BARIUM NITRATE	16

Figure 6. (C) 12.7-mm API Bullet B-32 (U).



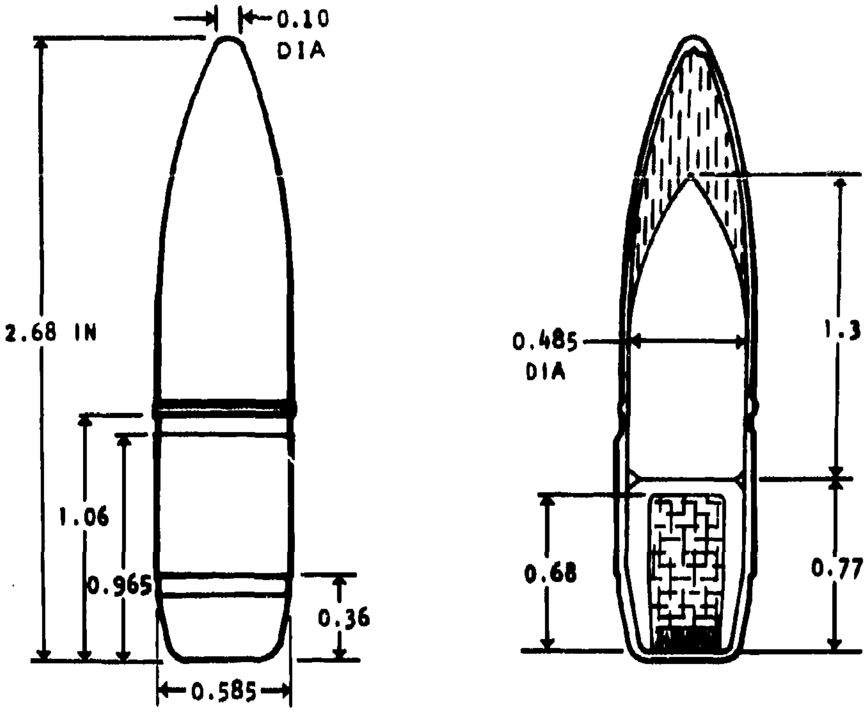
BULLET PART	MATERIAL	WEIGHT (GR)
JACKET	LOW CARBON STEEL, GILDING-METAL CLAD	176
CORE	HIGH CARBON STEEL	256
SHEATH	LEAD	98
INCENDIARY	ALUMINUM, MAGNESIUM, AND BARIUM NITRATE	16
TRACER CUP	MEDIUM CARBON STEEL, GILDING-METAL CLAD	105
TRACER IGNITER	MAGNESIUM AND BARIUM NITRATE	4
TRACER	ALUMINUM, MAGNESIUM, AND STRONTIUM NITRATE	22

Figure 7. (C) 12.7-mm API-T Bullet Type BZT (U).



BULLET PART	MATERIAL	WEIGHT (GR)
JACKET	LOW CARBON STEEL, GILDING-METAL CLAD	216
SLEEVE	LEAD	77
CORE	HIGH CARBON STEEL	633
INCENDIARY	ALUMINUM, MAGNESIUM, AND BARIUM NITRATE	19

Figure 8. (C) 14.5-mm API Bullet Type B-32 (U).



BULLET PART	MATERIAL	WEIGHT (GR)
JACKET	LOW CARBON STEEL, GILDING-METAL CLAD	271
CORE	HIGH CARBON STEEL	370
SHEATH	LEAD	75
INCENDIARY	ALUMINUM, MAGNESIUM, AND BARIUM NITRATE	24
TRACER CUP	LOW CARBON STEEL, GILDING-METAL CLAD	141
TRACER IGNITER	ALUMINUM, MAGNESIUM, AND BARIUM OXIDE	5
TRACER	ALUMINUM, MAGNESIUM, AND STRONTIUM NITRATE	28

Figure 9. (C) 14.5-mm API-T Bullet Type BZT (U).

TABLE II. (C) ARMOR PENETRATION DATA, 7.62 MM BALL CARTRIDGE, M1943 TYPE PS (U)

A - Variable Range	Material	Muzzle Velocity (m/sec)	Range (m)	Material Thickness (in.) Obliquity (deg) 0	30	45	60
	Homogeneous steel	710*	0	0.116	0.086	0.056	0.036
			100	.106	.079	.052	.034
			300	.086	.064	.044	.029
			500	.070	.052	.036	.025
			1,000	.044			
	Homogeneous aluminum		0	.35	.26	.17	.11
			100	.32	.24	.16	.10
			300	.26	.19	.13	.09
			500	.21	.16	.11	.08
			1,000	.13			

*For a muzzle velocity of 735 m/sec, increase all penetrations by 7 percent.

B - Variable Velocity	Material	Plate Thickness (in.)	Velocity (m/sec)	Obliquity (deg) 0	30	45	60
	Homogeneous steel	0.020	710	Y	Y	Y	Y
			610	Y	Y	Y	Y
			305	Y	Y	Y	N
		.125	710	N	N	N	N
			610	N	N	N	N
			305	N	N	N	N
		.50	710	N	N	N	N
			610	N	N	N	N
			305	N	N	N	N
	Homogeneous aluminum	.020	710	Y	Y	Y	Y
			610	Y	Y	Y	Y
			305	Y	Y	Y	Y
		.125	710	Y	Y	Y	N
			610	Y	Y	Y	N
			305	Y	Y	N	N
		.50	710	N	N	N	N
			610	N	N	N	N
			305	N	N	N	N

NOTE: Y = Projectile penetration
N = No projectile penetration

TABLE III. (C) ARMOR PENETRATION DATA, 7.62-MM BALL CARTRIDGE, M1943 TYPE LPS (U)

A - Variable Range

Material	Muzzle Velocity (m/sec)	Range (m)	Material Thickness (in.) Obliquity (deg) 0	30	45	60
Homogeneous steel	825*	0	0.255	0.189	0.123	0.079
		100	.233	.174	.115	.075
		300	.189	.141	.097	.064
		500	.154	.114	.079	.055
		1,000	.097			
Homogeneous aluminum		0	.76	.57	.37	.24
		100	.70	.52	.34	.22
		300	.57	.42	.29	.19
		500	.46	.34	.24	.16
		1,000	.29			

*Represents the average muzzle velocity of various weapons firing this cartridge. For a muzzle velocity of 805 m/sec, decrease all penetrations 5%; for a muzzle velocity of 850 m/sec, increase all penetrations by 6%.

B - Variable Velocity

Material	Thickness (in.)	Velocity (m/sec)	Obliquity (deg) 0	30	45	60
Steel	0.020	825	Y	Y	Y	Y
		610	Y	Y	Y	Y
		305	Y	Y	Y	Y
	.125	710	Y	Y	N	N
		610	Y	Y	N	N
		305	N	N	N	N
	.50	710	N	N	N	N
		610	N	N	N	N
		305	N	N	N	N
Aluminum	.020	710	Y	Y	Y	Y
		610	Y	Y	Y	Y
		305	Y	Y	Y	Y
	.125	710	Y	Y	Y	Y
		610	Y	Y	Y	Y
		305	Y	Y	Y	N
	.50	710	Y	Y	Y	N
		610	Y	N	N	N
		305	N	N	N	N

NOTE: Y = Projectile penetration
N = No projectile penetration

TABLE IV. (C) ARMOR PENETRATION DATA, 7.62-MM API CARTRIDGE, M1943 TYPE B2 (U)

A - Variable Range

Material	Muzzle Velocity (m/sec)	Range (m)	Material Thickness (in.) Obliquity (deg) 0	30	45	60
Homogeneous steel	710*	0	0.38	0.28	0.18	0.12
		100	.33	.24	.15	.10
		300	.24	.18	.12	.08
		500	.18	.14	.10	.06
Homogeneous aluminum		0	1.14	.84	.54	.36
		100	.99	.72	.45	.30
		300	.72	.54	.36	.24
		500	.54	.42	.30	.18

* For a muzzle velocity of 735 m/sec, increase all penetrations by 7%.

B - Variable Velocity

Material	Thickness (in.)	Velocity (m/sec)	Obliquity (deg) 0	30	45	60
Steel	0.020	710	Y	Y	Y	Y
		610	Y	Y	Y	Y
		305	Y	Y	Y	Y
	.125	710	Y	Y	Y	N
		610	Y	Y	Y	N
		305	Y	N	N	N
	.50	710	N	N	N	N
		610	N	N	N	N
		305	N	N	N	N
Aluminum	.020	710	Y	Y	Y	Y
		610	Y	Y	Y	Y
		305	Y	Y	Y	Y
	.50	710	Y	Y	Y	N
		610	Y	Y	N	N
		305	N	N	N	N

NOTE: Y = Projectile Penetration

N = No Projectile Penetration

TABLE V. (C) ARMOR PENETRATION DATA, 7.62-MM API CARTRIDGE, TYPE B-32 (U)

A Variable Range	Material	Muzzle Velocity (m/sec)	Range (m)	Material Thickness (In.) Obliquity (deg) 0	30	45	60
	Homogeneous steel	855*	0	0.70	0.51	0.33	0.22
			100	.61	.44	.28	.19
			300	.44	.33	.22	.15
			500	.34	.26	.19	.12
			1,000	NA	NA	NA	NA
	Homogeneous aluminum		0	2.11	1.54	1.00	.66
			100	1.82	1.31	.86	.57
			300	1.31	1.00	.66	.46
			500	1.03	.77	.57	.37
			1,000	NA	NA	NA	NA

*Represents the average muzzle velocity of various weapons firing this cartridge. For a muzzle velocity of 820 m/sec, decrease all penetrations by 8%; for a muzzle velocity of 865 m/sec, increase all penetrations by 2%.

B - Variable Velocity	Material	Thickness (in.)	Velocity (m/sec)	0	30	45	60
	Homogeneous steel	0.020	855	Y	Y	Y	Y
			610	Y	Y	Y	Y
			305				
		.125	855	Y	Y	Y	Y
			610	Y	Y	Y	Y
			305				
		.50	855	Y	Y	N	N
			610	N	N	N	N
			305				
	Homogeneous aluminum	.020	855	Y	Y	Y	Y
			610	Y	Y	Y	Y
			305				
		.125	855	Y	Y	Y	Y
			610	Y	Y	Y	Y
			305				
		.50	855	Y	Y	Y	Y
			610	Y	Y	Y	N
			305				

NOTE: Y = Projectile penetration N = No projectile penetration

TABLE VI. (C) ARMOR PENETRATION DATA, 12.7-MM API CARTRIDGE, TYPE B-32 (U)

A - Variable Range	Material	Muzzle Velocity (m/sec)	Range (m)	Material Thickness (in.) Obliquity (deg) 0	30	45	60
	Homogeneous steel	840	0	1.16	0.86	0.56	0.36
			100	1.06	.79	.52	.34
			300	.86	.64	.44	.29
			500	.70	.52	.36	.25
	Homogeneous aluminum		0	3.49	2.59	1.68	1.09
			100	3.18	2.37	1.56	1.03
			300	2.59	1.93	1.31	.87
			500	2.09	1.56	1.09	.75

B - Variable Velocity	Material	Thickness (in.)	Velocity (m/sec)	0	30	45	60
	Homogeneous steel	0.020	840	Y	Y	Y	Y
			610	Y	Y	Y	Y
			305				
		.125	840	Y	Y	Y	Y
			610	Y	Y	Y	Y
			305				
		.50	840	Y	Y	Y	N
			610	Y	N	N	N
			305				
	Homogeneous aluminum	.020	840	Y	Y	Y	Y
			610	Y	Y	Y	Y
			305				
		.125	840	Y	Y	Y	Y
			610	Y	Y	Y	Y
			305				
		.50	840	Y	Y	Y	Y
			610	Y	Y	Y	Y

NOTE: Y = Projectile penetration
N = No projectile penetration

TABLE VII. (C) ARMOR PENETRATION DATA, 12.7-mm API-T CARTRIDGE, TYPE BZT (U)

A - Variable Range	Material	Muzzle Velocity (m/sec)	Range (m)	Material Thickness (in.) Obliquity (deg) 0	30	45	60
	Homogeneous steel	840	0	0.68	0.50	0.32	0.21
			100	.60	0.45	.29	.19
			300	.49	0.36	.24	.17
			500	.38	0.29	.21	.14
	Homogeneous aluminum		0	2.03	1.50	.97	.62
			100	1.81	1.34	.87	.56
			300	1.47	1.09	.72	.50
			500	1.15	.87	.62	.41

B - Variable Velocity	Material	Thickness (in.)	Velocity (m/sec)	Obliquity (deg) 0	30	45	60
	Homogeneous steel	0.020	840	Y	Y	Y	Y
			610	Y	Y	Y	Y
			305				
		0.125	840	Y	Y	Y	Y
			610	Y	Y	Y	Y
			305				
		0.50	840	Y	Y	N	N
			610	N	N	N	N
			305				
	Homogeneous aluminum	0.020	840	Y	Y	Y	Y
			610	Y	Y	Y	Y
			305				
		0.125	840	Y	Y	Y	Y
			610	Y	Y	Y	Y
			305				
		0.50	840	Y	Y	Y	Y
			610	Y	Y	Y	Y

NOTE: Y = Projectile penetration
N = No projectile penetration

TABLE VIII. (C) ARMOR PENETRATION DATA, 14.5-MM API CARTRIDGE, TYPE B32 (U)

A - Variable Range	Material	Muzzle Velocity (m/sec)	Range (m)	Material Thickness (in.) Obliquity (deg) 0	30	45	60
	Homogeneous steel	1,000	0	1.29	0.97	0.64	0.51
			100	1.18	.89	.59	.39
			300	1.06	.83	.57	.38
			500	.94	.75	.52	.36
			1,000	.59			
	Homogeneous aluminum		0	3.87	2.97	1.92	1.23
			100	3.54	2.67	1.77	1.17
			300	3.18	2.49	1.71	1.14
			500	2.82	2.25	1.56	1.08
			1,000	1.77			

b - Variable Velocity	Material	Thickness (in.)	Velocity (m/sec)	Obliquity (deg) 0	30	45	60
	Homogeneous steel	0.020	1,000	Y	Y	Y	Y
			610	Y	Y	Y	Y
			305				
		.125	1,000	Y	Y	Y	Y
			610	Y	Y	Y	Y
			305				
		.50	1,000	Y	Y	Y	N
			610	Y	N	N	N
			305				
	Homogeneous aluminum	.020	1,000	Y	Y	Y	Y
			610	Y	Y	Y	Y
			305				
		.50	1,000	Y	Y	Y	Y
			610	Y	Y	Y	Y
			305				

NOTE: Y = Projectile penetration
N - No projectile penetration

TABLE IX. (C) ARMOR PENETRATION DATA, 14.5-MM API-T CARTRIDGE, TYPE BZT (U)

A- Variable Range

Material	Muzzle Velocity (m/sec)	Range (m)	Material Thickness (in.) Obliquity (deg) 0	30	45	60
Homogeneous steel	1,000	0	0.76	0.56	0.36	0.23
		100	.67	.50	.33	.22
		300	.60	.45	.31	.20
		500	.51	.38	.26	.18
		1,000	.32			
Homogeneous aluminum		0	2.28	1.68	1.08	.69
		100	2.01	1.50	.99	.66
		300	1.80	1.35	.93	.60
		500	1.53	1.14	.78	.54
		1,000	.96			

B- Variable Velocity

Material	Thickness (in.)	Velocity (m/sec)	Obliquity (deg) 0	30	45	60
Homogeneous steel	0.020	1,000	Y	Y	Y	Y
		610	Y			
		305				
	.125	1,000	Y	Y	N	N
		610	Y			
		305				
	.50	1,000	Y	Y	N	N
		610	N			
		305				
Homogeneous aluminum	.020	1,000	Y	Y	Y	Y
		610	Y			
		305				
	.125	1,000	Y	Y	Y	Y
		610	Y			
		305				
	.50	1,000	Y	Y	Y	Y
		610	Y			
		305				

NOTE: Y = Projectile penetration
N = No projectile penetration

TABLE X. (C) SOVIET 14.5-MM ANTIAIRCRAFT MACHINE GUNS, ZPU-1, ZPU-2, AND ZPU-4 (U)

CHARACTERISTICS AND PERFORMANCE

	Single ZPU-1	Twin ZPU-2 (new mount)	Twin ZPU-2 (old mount)	Quad ZPU-4
Caliber (mm)	*14.5			
Length overall (ft)				
(travel position)	11.3	12.7	11.0	15.2
(firing position)	11.5	12.7	9.2	15.3
Height (ft) (travel position)	4.1	3.6	6.0	7.5
(firing position)	7.0	3.6	7.5	8.8
Weight (lb) (travel position)	910	1368	2190	3990
(firing position)	910	1429	1407	3990
Elevation (deg)	-8.5 to +88°	-15 to +85°	-3 to +90°	-8.5 to +90°
Traverse (deg)	*360			
Rate of fire (rd/min per barrel)				
(cyclic)	*600			
(practical)	*150			
Muzzle velocity	*3,281 ft/sec		*1,000 m/s	
Maximum range (vertical)	*16,400 ft		*5,000 m	
(horizontal)	*7,655 yd		*7,000 m	
Tactical AA range	*4,600 ft		*1,400 m	
Tracer burnout range (API-T)	*6,232 ft		*1,900 m	
Fire control (on carriage)				
AA fire	*Optical-mechanical computing sight			
Ground fire	*Telescope			
(off carriage)	*None			
Ammunition				
Types	*API(B-32), API-T(BZT), I-T(ZP), HEI(MDZ)			
Tracer color	Orange-red			
Weight of projectile, API(B-32; API-T(BZT)	*0.142 lb		0.064 kg	
Armor penetration				
0° obliquity (API)	550 yd *0.94 in.	(500 m) (24 mm)	1,100 yd *0.59 in.	(1,000 m) (15 mm)
Air transportable	Yes			
Associated electronic equipment	None			

*Applicable for each system.

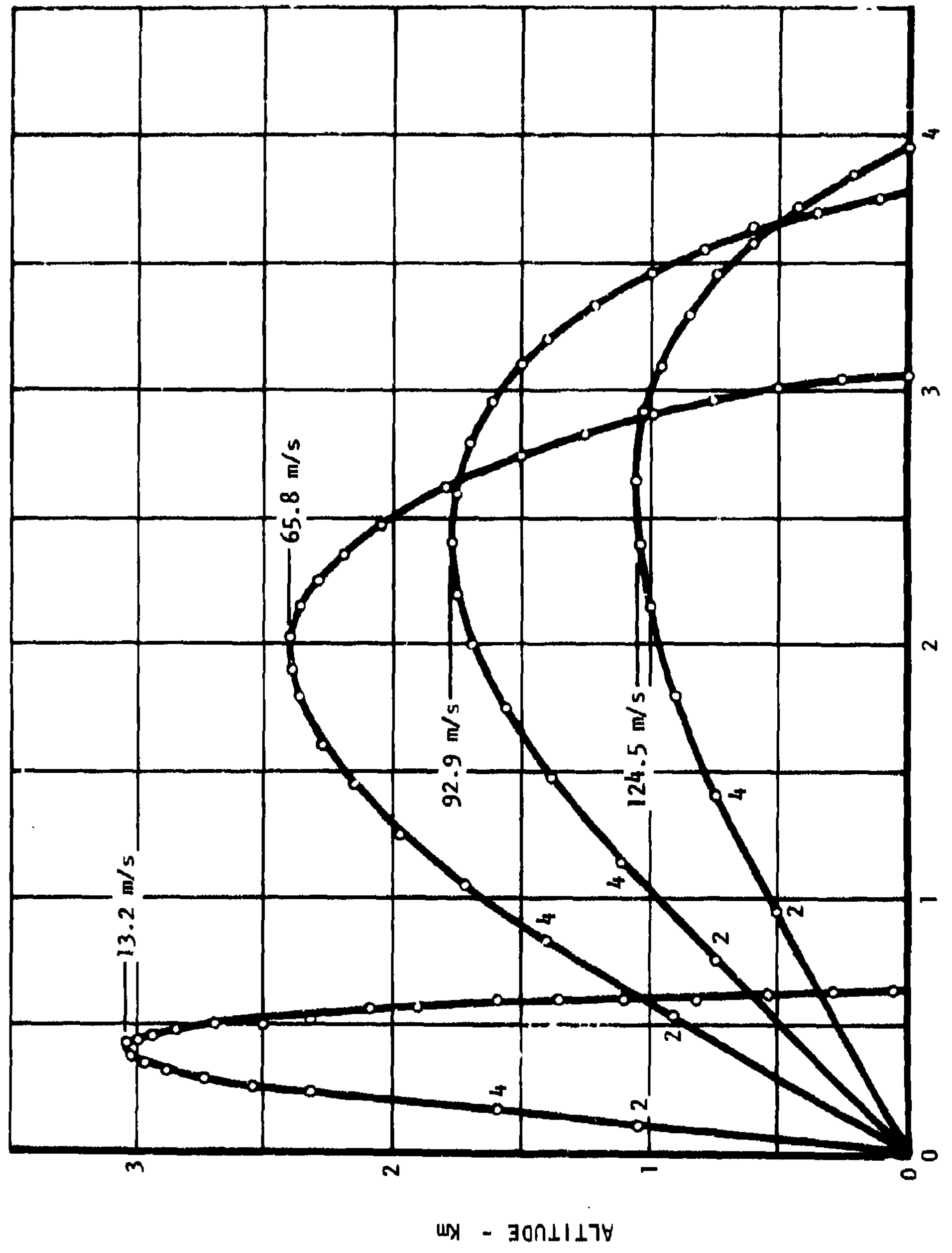


Figure 10. (C) 7.62-mm Heavy Machinegun SG-43/SGM (API Cartridge B-32) (U).

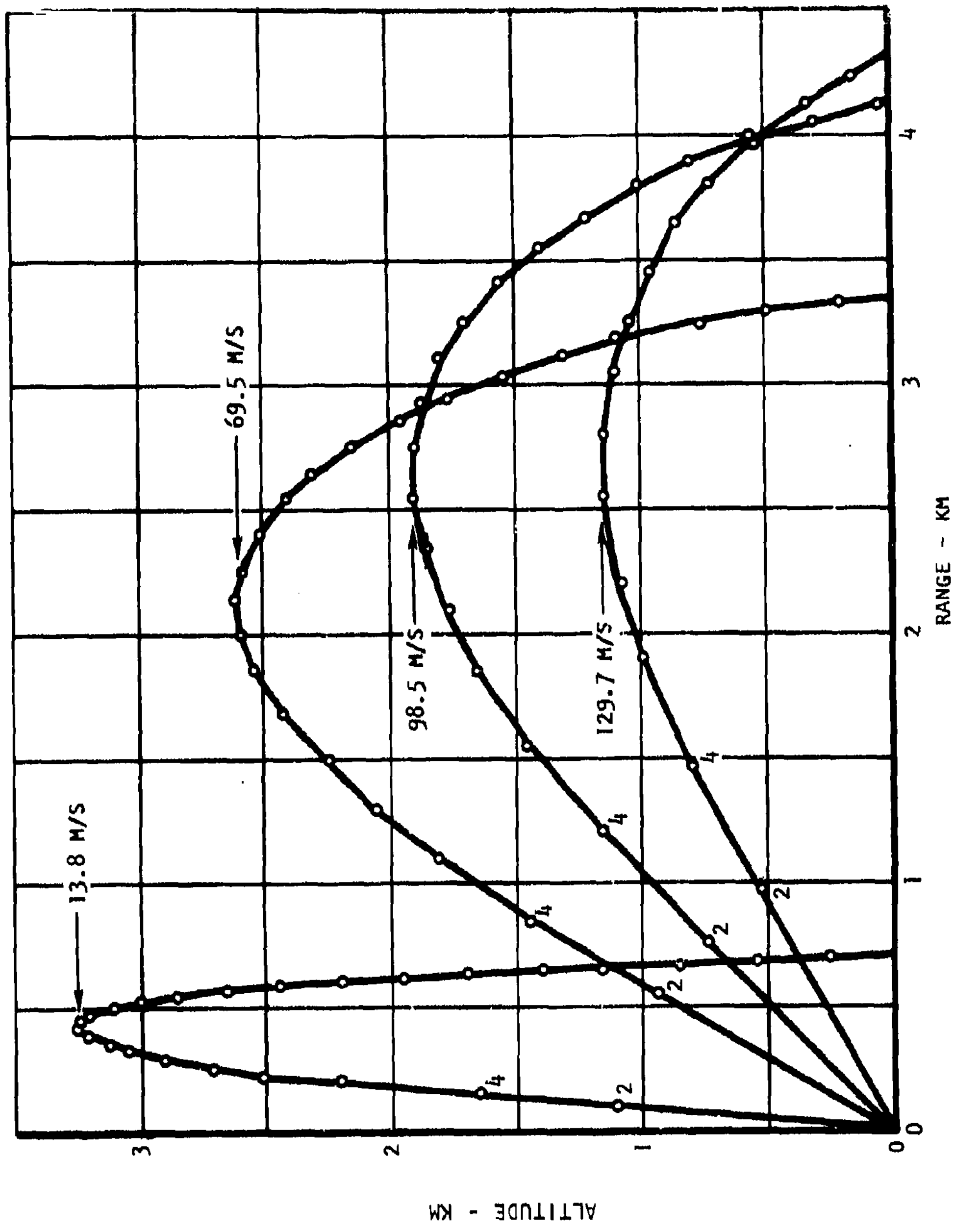


Figure 11. (C) 7.62-mm Machineguns SG-43/SGM, RP-46, and DP/DPM (Ball Cartridge LPS) (U).

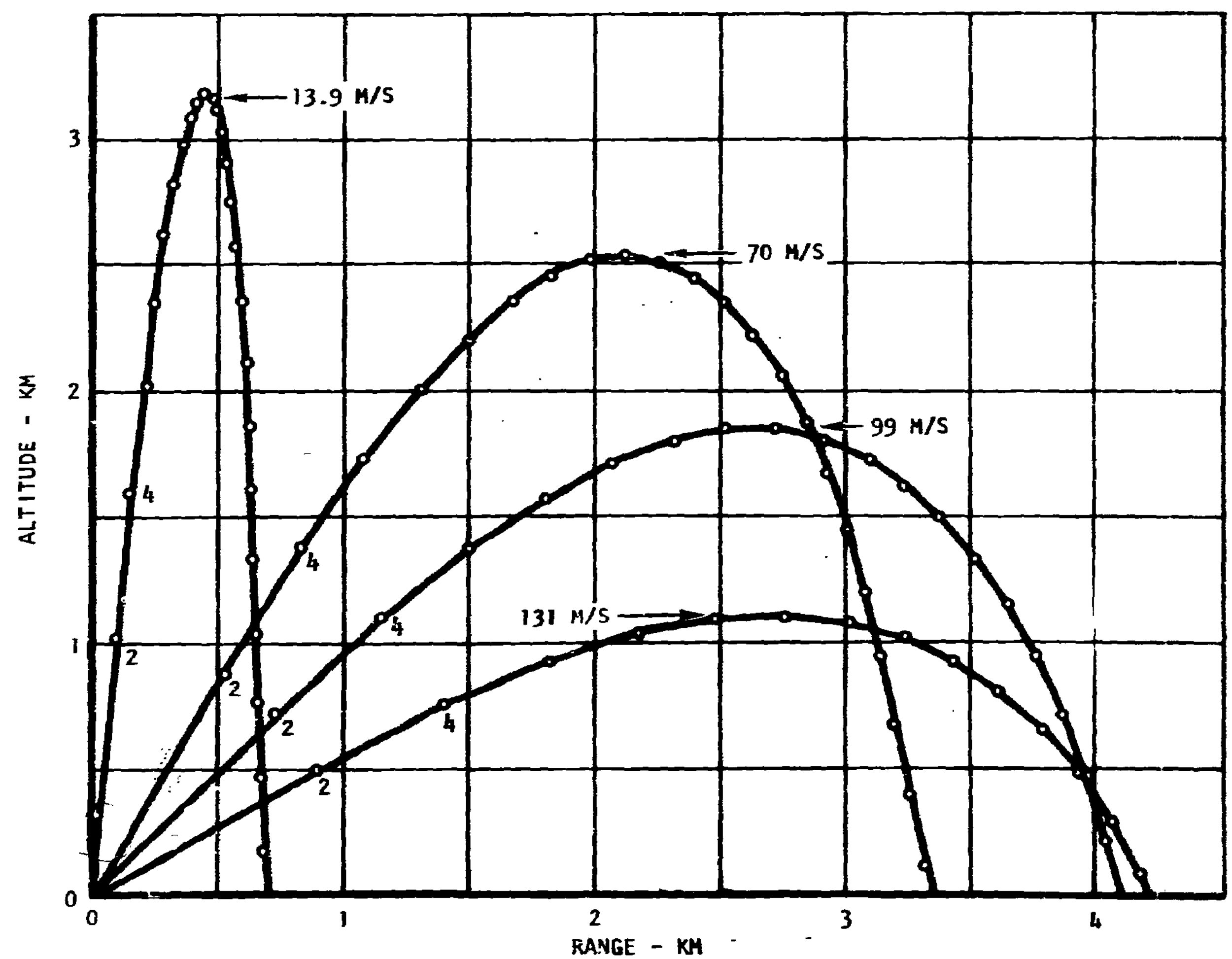


Figure 12. (C) 7.62-mm Heavy Machinegun M1908 Maxim (ChiCom Type 24) (Ball Cartridge M47) (U).

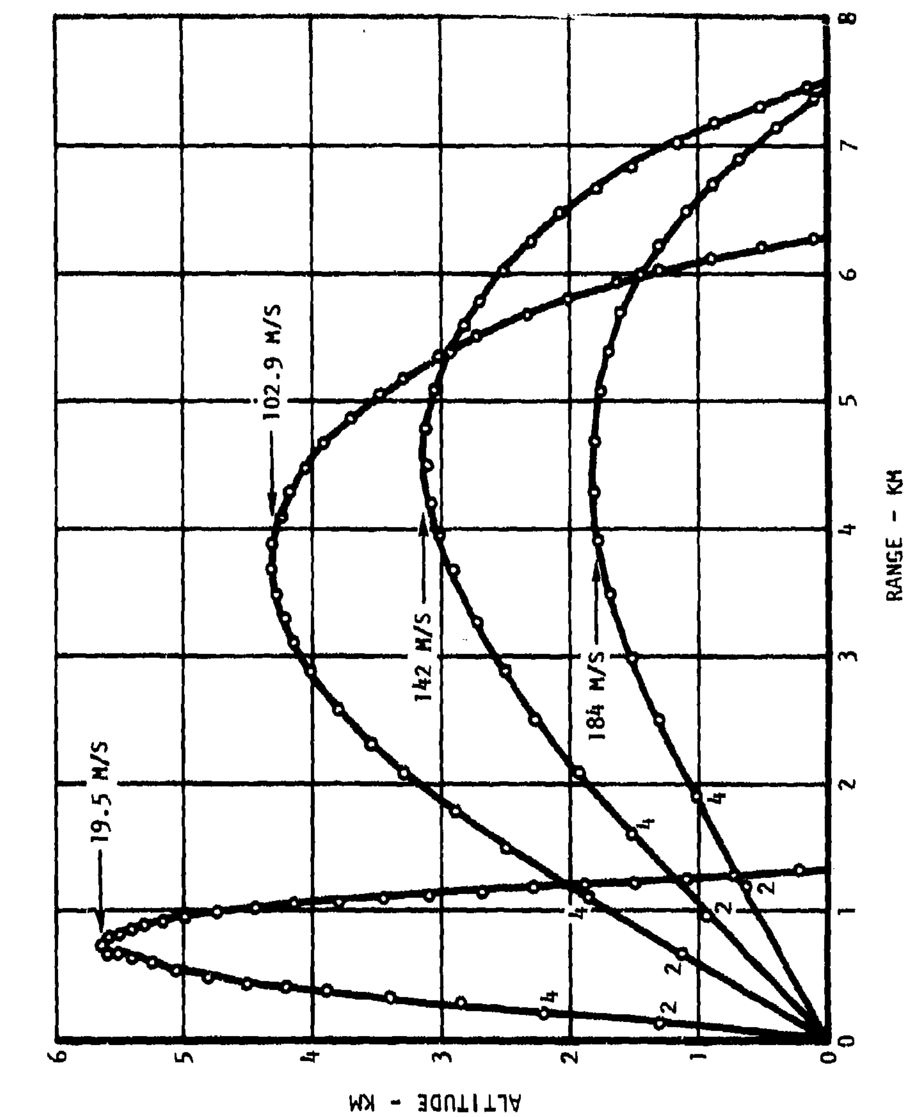


Figure 13. (C) 12.7-mm Heavy Machinegun M38/46 (API Cartridge B-32) (U).

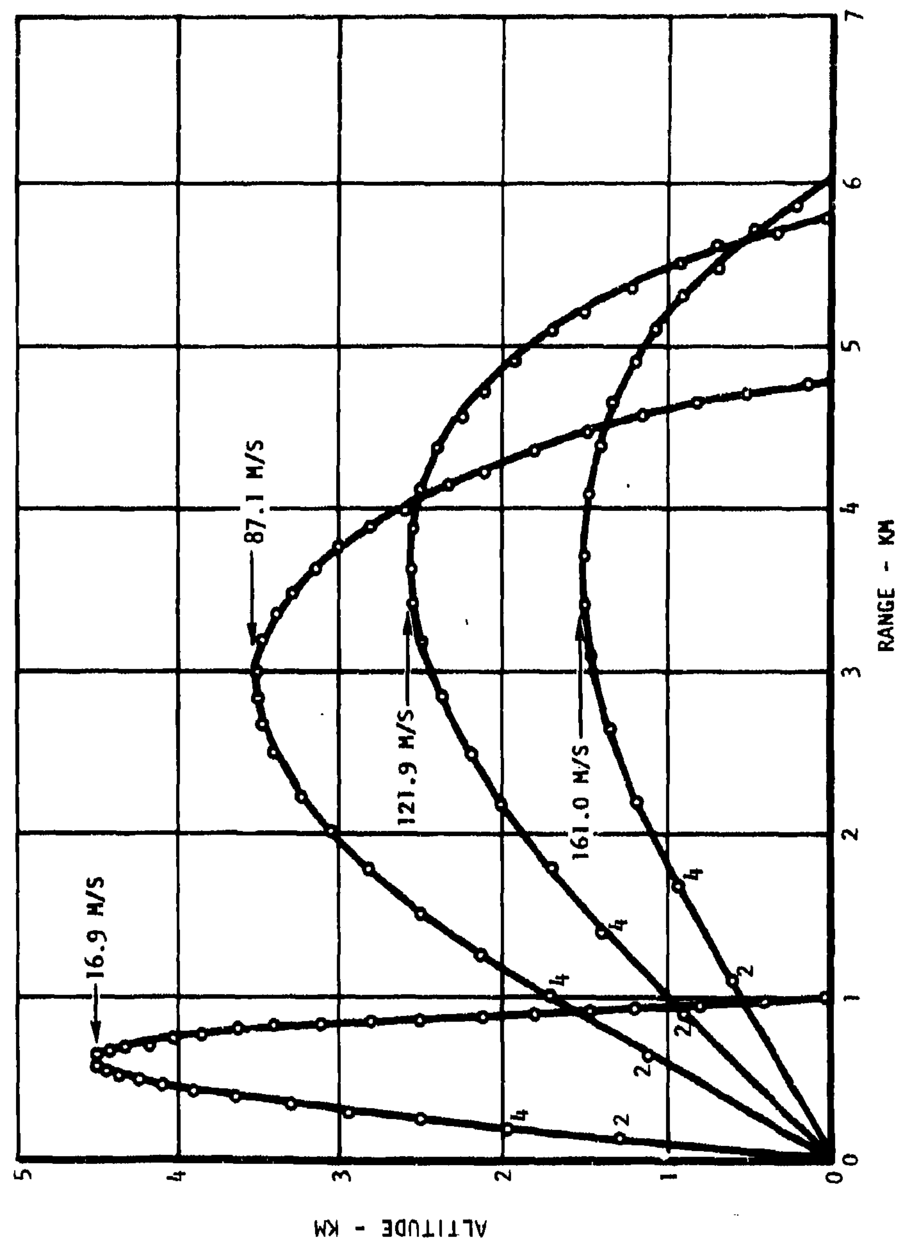


Figure 14. (C) .50 Caliber Machinegun Browning M2 (API Cartridge M-8) (U).

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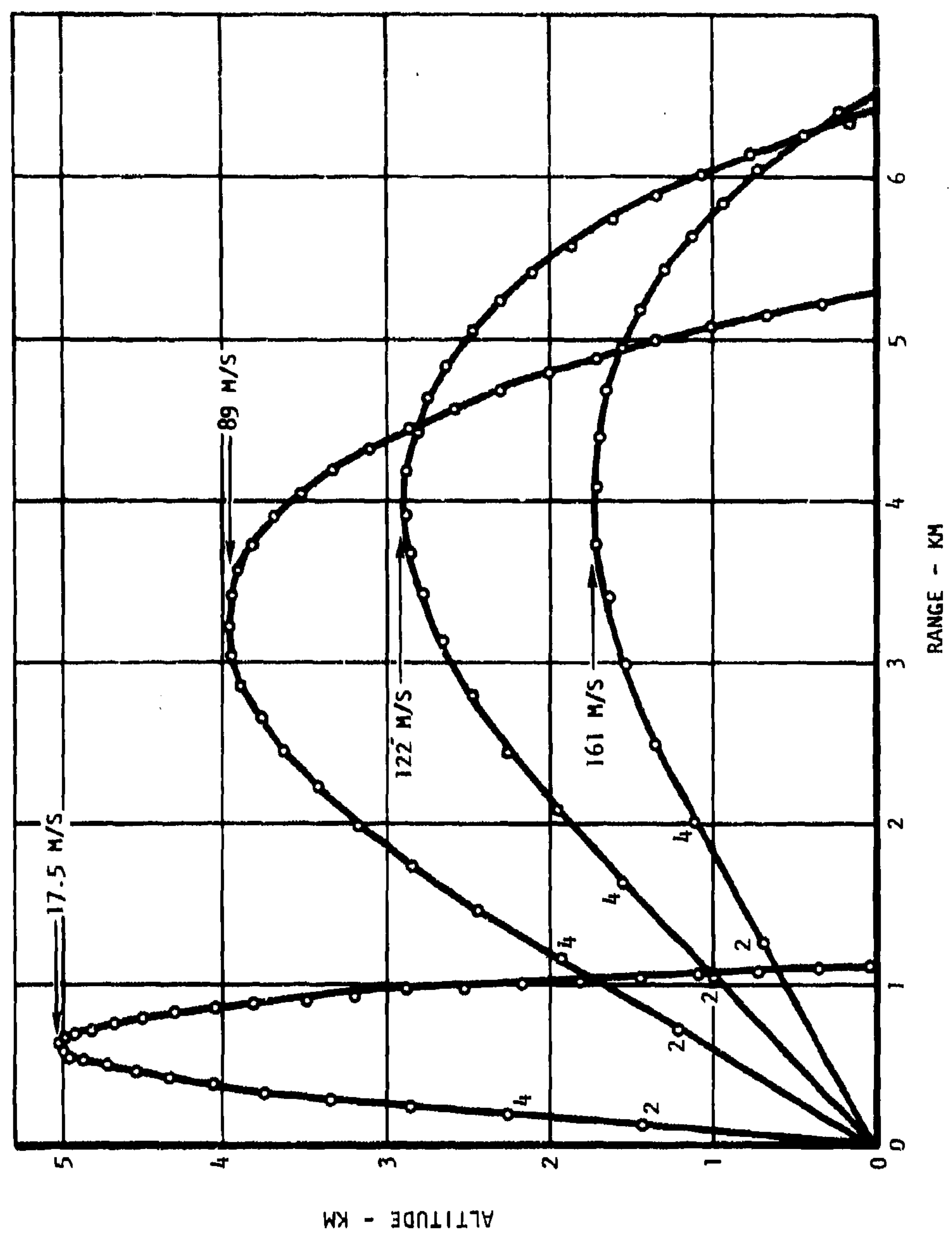

Figure 15. (C) 14.5-mm AA Heavy Machineguns ZPU-1, ZPU-2, and ZPU-4 (API Cartridge B-32) (U).

CHAPTER 3

(C) ARMOR MATERIALS CHARACTERISTICS (U)

3.1 (U) INTRODUCTION

(U) This section contains classified data on armor materials that supplements unclassified information contained in section 3 and Appendix II of Volume I (USAAMRDL Technical Report 71-41A).

3.2 (C) ARMOR TYPES (U)

(U) The following is classified information on armor types referenced to in Appendix II of Volume I.

3.2.1 (C) METAL-CERAMIC COMPOSITES (U)

(C) Limited information is available at this time regarding purely developmental work on two armors of this type. In one of these cases, mushroom-shaped inserts of alumina (Al_2O_3) are set in a perforated aluminum alloy and backed with a magnesium-lithium alloy. Preliminary tests indicate a velocity merit rating of approximately 1.85 against caliber .30 armor-piercing ammunition. In the case of the second, metal-ceramic composite, spheres, cylinders, and other noncoplanar ceramic shapes of Al_2O_3 alumina have been cast in aluminum. Preliminary work has indicated a velocity merit rating of about 1.5 can be obtained with this configuration, against caliber .30 armor-piercing ammunition. In both of these, additional developmental work is under way, but at the present time, neither of these composites can be seriously considered for immediate armor design purposes.

3.2.2 (C) METAL-ORGANIC COMPOSITES (U)

(C) This class of composite armor is at a stage where a screening program has been accomplished in which various metallic alloys (steel, titanium, aluminum, and magnesium) were backed with materials such as polyethylene, and bonded and unbonded nylon. To date, none of these composites have shown much promise, especially against small-arms armor-piercing projectiles.

3.2.3 (C) METAL-CERAMIC-ORGANIC COMPOSITES (U)

(C) Considerable work has been accomplished in recent years in the devel opment and ballistic testing of composites of this type. Foremost among these are those involving 94 percent alumina (Al_2O_3) in combination with aluminum alloys of the 2024, 5083, and 7039 categories and with 6Al-4V titanium alloy. Boron carbide (B_4C) in combination with 5083 aluminum alloy represents another composite of this type. While these composites are inferior to some of the ceramic-organic armors they do offer significantly higher merit ratings than most of the armors discussed previously.

3.2.4 (C) SAFETEE GLASS (U)

(C) Safetee glass is composed of two or more layers of glass bonded by a transparent organic material. It has good multihit capabilities against caliber .30 ball M2 projectiles. Approximately 17 lb/ft^2 areal density (2.25-inch thickness) is required for full protection against this threat. An areal density of approximately 30 psf would be required against caliber .30 AP M2 projectiles. The material cost is comparatively high compared with the cost of some of the more basic armors. Better materials are available, however.

3.2.5 (C) LAMINATED BONDED ORGANIC COMPOSITES (U)

(C) Some of the developments in this field represent significant improvements in the field of transparent armor. While a number of composites have been investigated, stretched Plexiglas is common to all of the best materials in this category. In general, the effectiveness of such armor against armor-piercing projectiles is largely due to the ability of the lamina to deflect the paths of projectiles rather than to break up the core, as is the case with hard-faced armors. These composites are not yet at the stage where they can be used for current armor designs. In general, however, it can be said that velocity merit ratings in the range of 1.0 and 1.1 against caliber .30 ball and armor-piercing projectiles are obtainable from the best of these composites.

3.2.6 (U) LAMINATED BONDED INORGANIC COMPOSITES

(U) Development work in this area has been more limited, and available data indicate that experimental armors of this type are little, if any, better than commercially available bullet-resistant glass.

3.2.7 (C) LAMINATED BONDED INORGANIC-ORGANIC COMPOSITES (U)

(C) Armors of this type are also called biphasic composites and glass-plastic composites. Included in this category are such materials as plate glass, Pyrex, chemically strengthened glasses, and fused silica in various combinations and configurations with Lexan, polyvinyl, butyral, Tedlor, etc. They represent a significant advance in transparent armor development, and provide velocity merit ratings as high as 1.36 against caliber .30 ball ammunition. In addition, composites in which the glass portion (phase) is chemically strengthened glass or fused silica, are effective for armor-piercing projectiles. Specifically, those containing fused silica are capable of velocity merit ratings up to approximately 1.2 against 7.62-mm AP M61 projectiles, according to early data.

3.2.8 (C) SPACED ARMOR PROTECTION MECHANISM (U)

(C) Basically, the special protection capabilities of spaced armor result from the very existence of the space itself. In some cases, additional advantage is gained from the type and arrangement of the elements that comprise the armor system. Although these differences do have an effect upon the details of the projectile penetration process and thus upon the mechanism by which the armor defeats the projectile threat, in general these processes are basically the same as in the case of solid armor.

(C) In general, the projectile penetration process becomes a multistep event, rather than a single process. Depending upon the nature of the first (outer) element of the spaced armor system, the protection mechanism may be solely one of energy absorption or it may, in addition, tend to produce projectile shatter and/or partial deflection. If and when the projectile or projectile fragment finally impacts inner elements of the armor system, the basic process is repeated; in this case with a projectile much of whose kinetic energy will have been spent. Individually, these separate penetration/protection mechanisms are similar to the basic ones discussed for solid armor. As in the case of solid armors, the details depend upon such factors as armor type, projectile type and size, impact velocity, impact obliquity, etc.

(U) A number of types of spaced armor systems have been evaluated for purposes of information. Five basic types of spaced armor are discussed briefly in the following paragraphs to give the designer some general information on this special type of armor. These basic types are:

a. (U) Angularly spaced homogeneous metal plates

b. (U) Drilled metal/Doron armor

c. (U) Tipping plate armor

d. (U) Hardened steel bar/steel plate spaced armor

e. (U) Ceramic spaced armor

3.2.9 (C) ANGULARLY SPACED HOMOGENEOUS METAL PLATES (U)

(C) Spaced armor of this type consists of homogeneous metal plates set at various distances apart and normally at a nominal obliquity of 45 degrees to each other. The front (outer) armor plate is normally set at the 45-degree angle to the probable projectile path, and the rear (inner) plate is positioned normal to the mounting structure or aircraft component being protected. A maximum velocity merit rating of 1.09 was obtained against 14.5 mm projectiles by a system of this type using a combination of armor steel and aluminum. No results of any testing against such systems using more advanced armor are currently available.

3.2.10 (U) DRILLED METAL/DORON ARMOR

(U) A second general type of spaced armor system is that composed of drilled metal frontal plates backed with Doron and spaced 4 inches in front of Doron stopping plates. An armor of this basic type has been used in one helicopter application. The best results to date showed a velocity merit rating of 1.14 against 7.62 mm ammunition at an areal density of 13.4 psf, using titanium as the drilled metal frontal plate. This excels the results obtained on similar drilled steel sheet/Doron arrays, which do not significantly excel standard steel armor.

3.2.11 (U) TIPPING PLATE ARMOR

(U) In spaced armor systems of this type, the success of the armor array depends upon tipping or tilting the impacting projectile so that it can then be retained by a stopping plate set some distance behind the tipping plate. Although such armors have been considered in certain aircraft (helicopter) applications, like most of the spaced armors, they presently offer greater potential in boat and land vehicle installations than for aircraft armor design.

3.2.12 (C) HARDENED STEEL BAR/STEEL PLATE SPACED ARMOR (U)

(C) Probably the most promising spaced armor system developed to date consists of various hardened steel bar arrangements spaced in front of aluminum or steel stopping plates at standoff distances ranging from

5 to 17 inches. Most of these arrays exhibit high-velocity merit ratings ranging from 1.3 to 1.4 against caliber .30 armor-piercing projectiles, and up to 2.05 against 14.5 mm API BS-41 projectiles. As mentioned in a more general way earlier in this section, ballistic limits, and thus merit ratings, for this type of armor have been subject to some degree of variation, and additional work is required in order to establish final values. Additional testing is also being done to arrive at an optimum configuration against caliber .50 armor-piercing ammunition.

(C) At this time and while the additional development work continues, armor of this type will not be immediately available. It is anticipated that when the armor becomes available, it will be reasonably low in cost and will be a good candidate for aircraft armor, especially because of a good multiple-hit capability and high-grade ballistic protection properties.

3.2.13 (C) CERAMIC SPACED ARMOR (U)

(C) A final general-type of spaced armor of current interest involves alumina spheres and cylinders imbedded in foamed plastic or aluminum honeycomb, and placed at a preselected distance in front of aluminum or bonded nylon armor plates. This developmental-type spaced armor has shown velocity merit ratings falling over a rather wide range, but high enough (over 1.5 in some cases) to warrant further consideration. Early results also indicate a possible advantage because of the probable ease with which damaged armor can be repaired.

3.3 (C) THREAT DEFEAT (U)

(U) There are two methods by which armor can defeat an attack by projectiles or fragments. The methods are energy-absorption mechanism and projectile shattering.

3.3.1 (C) ENERGY-ABSORPTION MECHANISM (U)

(C) In cases where energy absorption is the primary attack defeating mechanism, this absorption is accomplished principally by plastic flow of the armor plate, and is primarily a function of material hardness and ductility. (Material thickness and projectile impact obliquity are obviously additional considerations.) Ideally, the hardness should be high enough to insure that the plastic flow will occur at a high energy level. Similarly, the ductility should allow for maximum distortion of the armor before fracture. Unfortunately, ductility usually tends to decrease with increasing hardness; thus, there are practical limits which

must not be exceeded. Beyond this limit, effectiveness of the armor would be reduced by tendencies toward spalling, cracking, and even fracture of the material.

(U) In general, this energy-absorption mechanism is the primary defense offered by many of the lower hardness homogeneous materials, both metallic and nonmetallic. As a general rule, armors using this single defense mechanism tend to be more effective against ball-type projectiles and fragments than against armor-piercing projectiles, especially at the higher velocity/energy levels.

3.3.2 (C) PROJECTILE SHATTERING (U)

(C) At the higher projectile velocities, and especially in the case of armor-piercing projectiles, use of the energy-absorption mechanism as the sole device for defeating the threat tends to result in armor installations too heavy and/or too bulky for many aircraft applications. In response to this situation, much effort has been exerted to develop armor hard enough to shatter the attacking projectile upon impact. By using this defense mechanism, much of the energy of the projectile is spent prior to any significant penetration of the armor. Since the shattered projectile does, however, have some degree of energy left, this energy must be absorbed in order to prevent any possibility of complete penetration of the armor, as mentioned previously. This energy can only be absorbed by whatever armor remains behind the impact surface. In the case of homogeneous armor materials, this backup consists only of the unpenetrated basic material. In the case of armor systems, primarily composites, this backup material may consist of one or more layers comprising the backing portion of the composite plus any unpenetrated thickness of the outer layer (spall and fragment shield).

(U) Armors developed for and having some degree of capability for ballistic protection by initial shattering of the impacting projectile include some of the high-hardness homogeneous materials, face-hardened steels, and many of the composite armor systems. Because of the surface hardness required, consideration must be given to the possibility of danger from spalls or other secondary fragments, unless the material itself is of a basic nature to minimize such spalling or can be protected by a spall shield.

3.4 (C) ANALYSIS OF BALLISTIC VARIABILITY/RELIABILITY FACTORS (U)

3.4.1 (C) GENERAL (U)

(C) The standard criterion for establishing the ballistic performance of armor materials is the V_{50} ballistic limit (V_{50} BL). Currently, this is

a basis on which a designer can select an armor material to defeat a specified ballistic threat. It has been customary to overstate the ballistic requirement so that the armor material will have a high probability of defeating the impacting projectile at the anticipated (realistic) threat level. This approach is technically unsound, since the allowance made for ballistic variability of the armor is arbitararily established. However, it probably represents the best approach that could be taken, considering the available ballistic data.

(U) The ultimate solution to this problem is to provide the designer with measurements of both the true mean ballistic performance and variability of the armor materials. The designer will then be able to select the armor material that satisfies a specified ballistic requirement at an acceptable reliability (probability of success) level. The ballistic threat, as determined by vulnerability analysis, would be considered without arbitrary adjustment.

(U) A general discussion of various aspects of armor ballistic variability follows, with specific emphasis on statistical considerations.

3.4.2 (C) STATISTICAL SIGNIFICANCE OF ARMOR PERFORMANCE (U)

(C) Armor specimens that are identical in appearance and have been produced by the same production process often have different threshold velocities; i.e., resistances to projectile penetration. Even various locations on the same armor specimen may have unequal resistances to penetration. This lack of ballistic uniformity is due to random variability of many uncontrollable factors that exists in the fabrication of armor. In addition, some armor types have a greater spread of random variability than others. Thus, the probability distributions of penetration resistance of two types of armor may both have the same parameter average (V_{50} BL), above which 50 percent of the specimens are penetrated, and below which 50 percent are not penetrated by the projectile. But one of these two armors may have a lesser spread than the other armor; this means that although their two parameter V_{50} BL's are identical, their V_{10}'s may not be. Graphically, this anomaly may be portrayed as shown in Example 1 of Figure 16.

(C) Thus, those testing methods which compare and select from competing armors only on the basis of the V_{50} BL possess a dangerous omission of projectile velocities on either side of the V_{50} BL. To starkly delineate this danger, attention is directed to the portions of the two curves in Example 1 to the left of the V_{50} BL. It can be seen that armor A is superior to armor B, since the V_{10} of A exceeds the V_{10} of B; that is, the

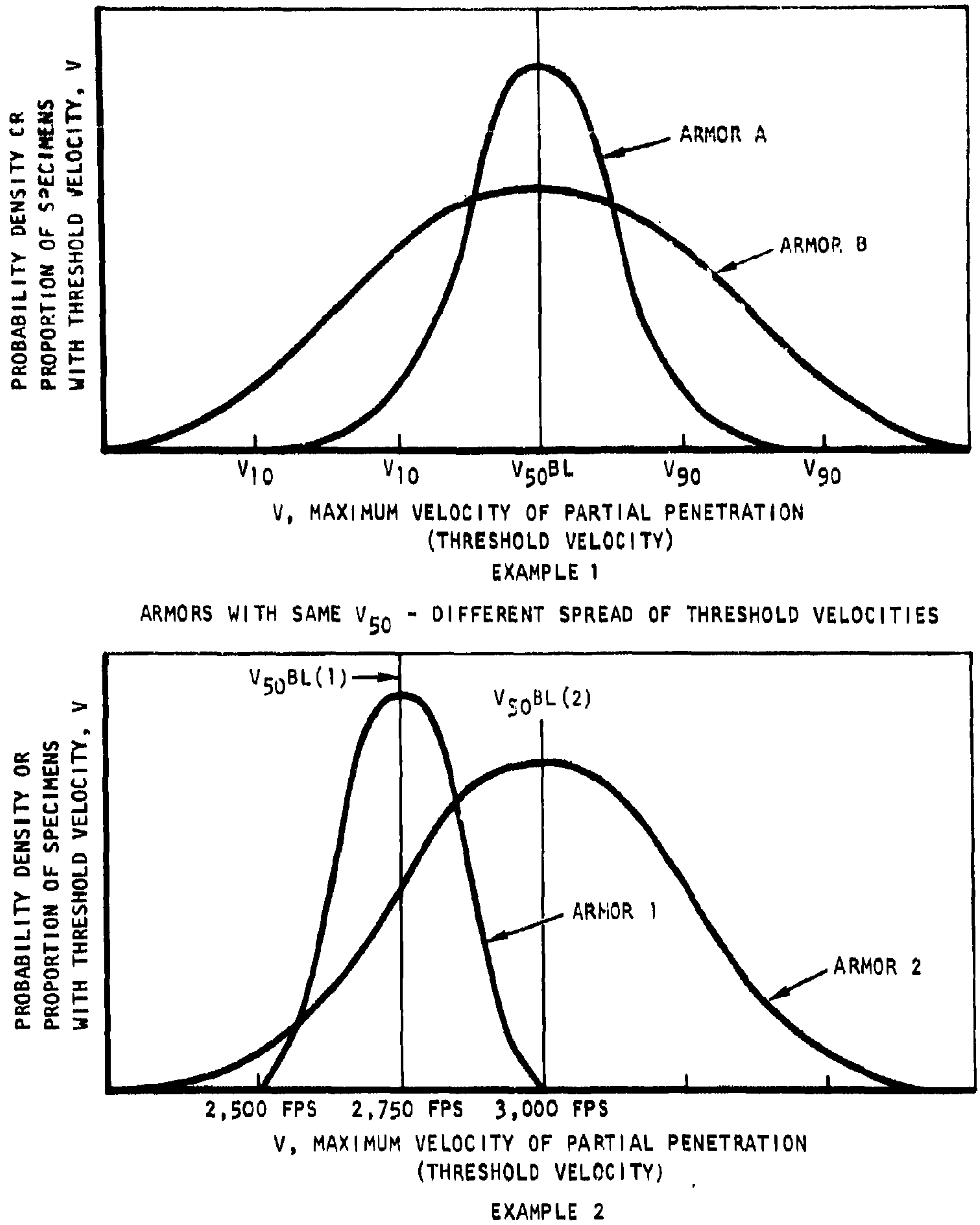

Figure 16. (C) Armor Performance (U).

velocity (V_{10}) at which 10 percent of the specimens would be penetrated is higher for armor A than B. Therefore, if in some actual combat application of armor the probability is high that projectile velocities will be less than the V_{50} BL, then armor A should be used. The reverse is also true: if projectile velocities will probably be higher than the V_{50} BL, then armor B should be used. (From knowledge of the terrain and enemy equipment and emplacements, operations analysts can estimate the probabilities of occurrence of various projectile velocities and obliquities.) In essence, one of the basic laws of the statistical analysis of data must be considered in ballistic tests and in design of protective armor systems; namely, both the average and a measure of spread must be estimated for proper armor evaluation. (This is true only for symmetric, normal distributions.) The common and best statistical measure of spread is the standard deviation.

(C) When both the V_{50} BL's and the spreads (standard deviation) of two armors are unequal, the problem is further compounded, but not impossibly so. In the second example shown in Figure 16, armor 2 has a higher V_{50} BL and larger spread than armor 1; nevertheless, armor 1 is superior in defeating projectile velocities of 2,500 fps or less.

(U) In summary, the proper analysis, testing, and design of armor systems require estimates of the V_{50} BL, the spread of penetration resistances, and the probability of occurrence of various projectile velocities and obliquities.

3.4.3 (C) ESTIMATING THRESHOLD VELOCITY DISTRIBUTIONS (U)

(C) Since an armor specimen cannot be continuously subjected to a series of projectile impacts of increasing velocity to discover its threshold velocity, it would appear that this important, inherent property is not measurable. Indirectly, however, it is measurable by statistical procedures known as "sensitivity tests" of "quantal response testing." The simple basis from which these tests derive the probability distribution of threshold velocities is the fact that if a large number of specimens were randomly selected and all subjected to the same projectile velocity (2,500 fps, for example) then the proportion of penetrated specimens would be the proportion of specimens with threshold velocities less than 2,500 fps. If additional large samples of armor specimens were subjected to other projectile velocities, the entire probability distribution of the threshold velocity of the armor could be established from a plot of these data on probability paper. From this plot, similar to that shown in Figure 17, the mean (V_{50} BL) and the measure of spread (standard deviation) can be computed by statistical methods.

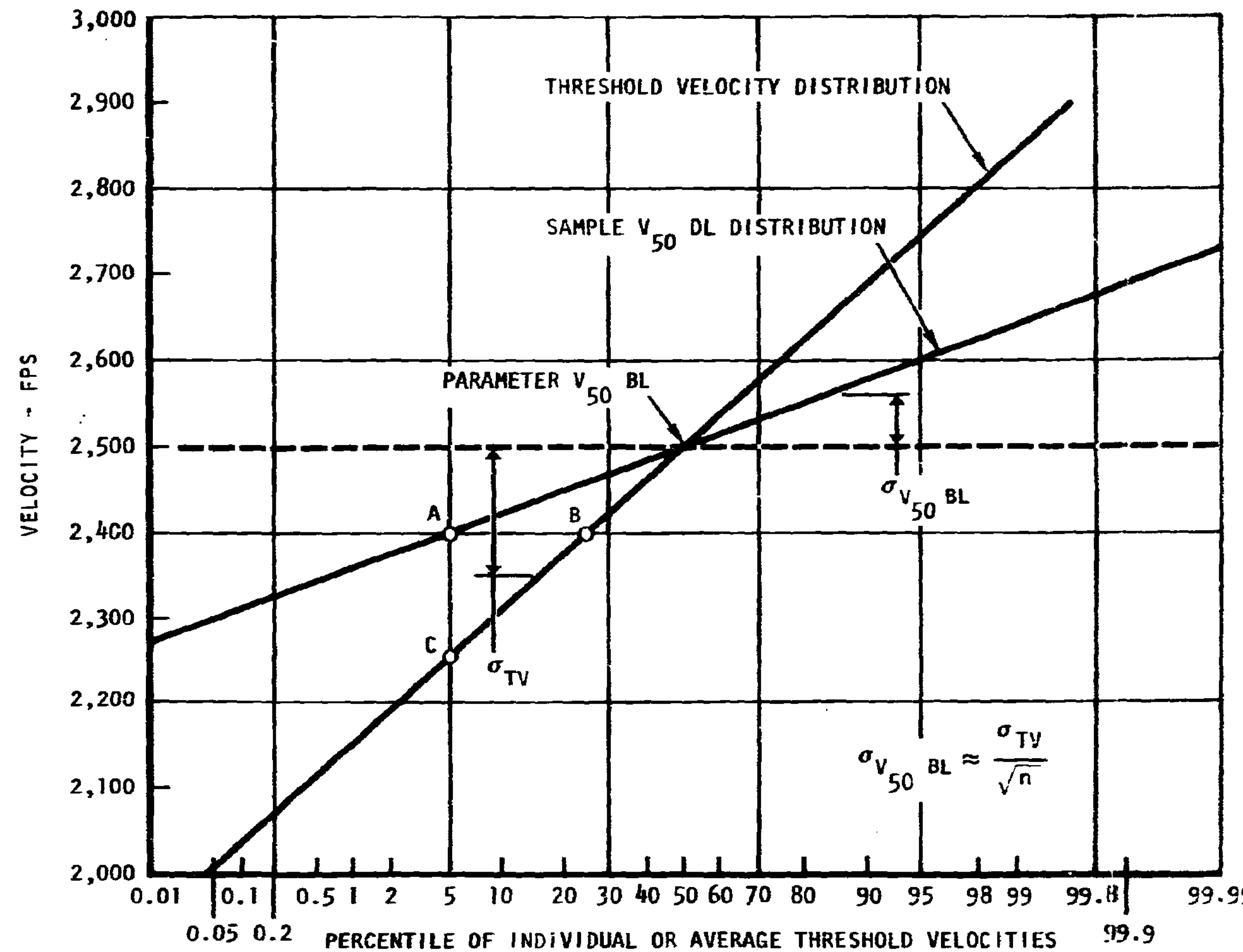

Figure 17. (C) Distributions of Threshold Velocities and V_{50} Averages of Sample Size "N" (U).

3.4.3.1 (C) Relationship Between the Standard Deviations of Individual Specimens and Sample Averages (U): (C) The standard deviation of threshold velocities can be related to the standard deviation of a sample average, V_{50} BL, computed from n-tested specimens by a statistical "law." This law relates the standard deviation, σ_{TV}, of individual single random variables to the standard deviation of sample averages, V_{50} BL, n-specimens by the formula:

$$V_{50} \text{ BL} = K \frac{\sigma_{TV}}{n}$$

The K-factor here is unity when the n-values are drawn completely at random. But in V_{50} BL testing, a critical range is imposed, and some data are thereby selected and discarded. Therefore, the K-factor is an unknown quantity that requires further mathematical research to establish its dependence on the rules of ballistic testing. However, when the range is sufficiently wide and very few values are discarded, the K-factor will approach unity. Then the formula with K = 1 may be used to estimate what critical V_{50} BL value the sample average must exceed for some specified reliablity (probability of success) against a designated projectile velocity threat.

(C) Let us assume, for example, that sensitivity testing has established that an armor system at a particular areal density exhibits a V_{50} BL of 2,500 fps and a standard deviation of threshold velocities, σ_{TV}, of 150 fps. Using the equation stated previously the V_{50} BL is equal to 61 fps when n = 6 (six-shot V_{50} BL). This information, plotted on probability paper (Figure 17), defines the reliability-velocity relationship.

(C) From this graphic presentation, it can be seen that the V_{05} (5 percent probability of complete penetration) of the individual specimens is 2,250 fps (point C). To assure that this level of protection is achieved, a minimum sample V_{50} BL of 2,400 fps (point A) must be realized. Note also that, for the particular example chosen, there is a 25-percent probability of complete penetration of individual specimens at 2,400 fps (point B), but only a 5-percent chance of a V_{50} BL below this level. The minimum V_{50} BL value that will be exceeded with probability P for a selected reliability against individual impacts can be computed from the relationship:

$$V_X = \frac{\sigma_{TV}}{n} Z_{p\%} + V_{50} \text{ BL}$$

where $Z_{p\%}$ is the p^{th} percentile from tables of the cumulative standard, unit normal distribution.

(U) All these calculations assume that sensitivity tests were conducted on large numbers of test specimens to obtain precision values of σ_{1V}.

3.4.3.2 (C) Small Sample Statistics (U): (C) Large sample sizes are rarely available for testing; very small samples are the general rule. Thus, the variability of estimates from small samples enters the problem, since the small sample V_{50} BL's (or sample standard deviations) will differ considerably from their parameter values. The proper statistical procedure then is to use confidence limit estimates of the population parameters of the armor. These parameters are the values of the mean and the standard deviation, if indeed an infinite sample size of specimens (the population) were tested. It is these population parameters, not the V_{50} BL of a sample, that are of paramount concern, since they characterize the hugh number of armor units that will be produced in the future. Obviously, the sample V_{50} BL may by chance deviate considerably from the population mean. Therefore, confidence limits computed from the sample provide statements such as: "With a 95-percent confidence, the population V_{50} BL is between 2775 and 2832 feet per second." This means that there is only a 5-percent probability that the population mean is not between these two limits. Or it may be stated that the V_{50} BL will exceed, 2,800 fps, with a confidence of 90 percent - there being only a 10-percent chance that the population V_{50} BL is less than 2,800 fps. If some other population value, such as V_{10}, is of interest, then confidence limits at this level may be similarly computed. The class of statistical method that provides the afore type of confidence limits is called Tolerance Limit Estimates.

3.4.3.3 (C) Deficiencies of Current V_{50} BL Testing (U): (C) The V_{50} BL testing procedure referred to is that which requires three partial and three complete penetrations within a velocity range of 150 fps. These six velocities are then averaged, and this value is used as V_{50} BL. The deficiencies of this method are numerous, and results are severely erroneous from both statistical and practical standpoints. The deficiencies are:

a. Two armors may have the same parameter V_{50} BL, yet not be equally protective against some spectrum of projectile velocities. A better and more important parameter is the condition where the probability of success (reliability) is high, such as V_{05}, for projectile defeat.

b. Sampling variability of small sample V_{50} BL estimates is ignored.

c. The sample V_{50} BL is used as a parameter, whereas it could by chance be quite distant from the true parameter V_{50} BL.

d. Some ballistic data (i.e., those results outside the specified velocity range) are discarded. All ballistic data should be used to define the ballistic parameters of the armor.

e. The sample V_{50} BL can be intentionally or unintentionally biased, depending on the selected starting velocity during ballistic evaluation. The extent of this bias is related to the magnitude of the standard deviation of threshold velocities.

3.5 (C) PROJECTING BALLISTIC PERFORMANCE (U)

(C) The ability to predict accurately the performance of armor materials and systems against various ballistic threats is of obvious interest to armor development and design engineers. A theory of the mechanics of penetration is needed that will describe performance in terms of armor and projectile characteristics. Significant progress has been made in the area of the behavior of homogeneous armor. The application of penetration theory to composite armor systems, particularly those with brittle ceramic facings, will require more study. The response to ballistic impact of both the ceramic facings and reinforced plastic backings typical of composite armor systems is a complex phenomenon. It is anticipated that ultimately a mechanics of penetration theory will be developed for such armor that will accurately define the projectile-target interactions.

(C) It is desirable to establish a general relationship between ballistic performance and areal density that will benefit the armor development and design engineers while penetration theory is being definitized. A method is described that can be used to predict armor ballistic performance against artillery armor-piercing rounds. This method involves the relationship between the kinetic energy of steel penetrators and armor areal density required to defeat the projectile at service muzzle velocity (0-yard range) and 0-degree obliquity. Log-log plots of kinetic energy and areal density are presented for homogeneous steel and several composite armor systems. Linearity of the curves on the log-log plot is evident over the broad range of areal densities shown.

(C) Since this relationship is applicable only to steel penetrators, it has some obvious limitations. By a rather simple modification to this approach, a relationship of greater utility was developed. The modification consists of dividing the input kinetic energy of the penetrator by the cross-sectional area of the penetrator. This modified relationship is shown in Figure 18, in which specific data points are shown for the

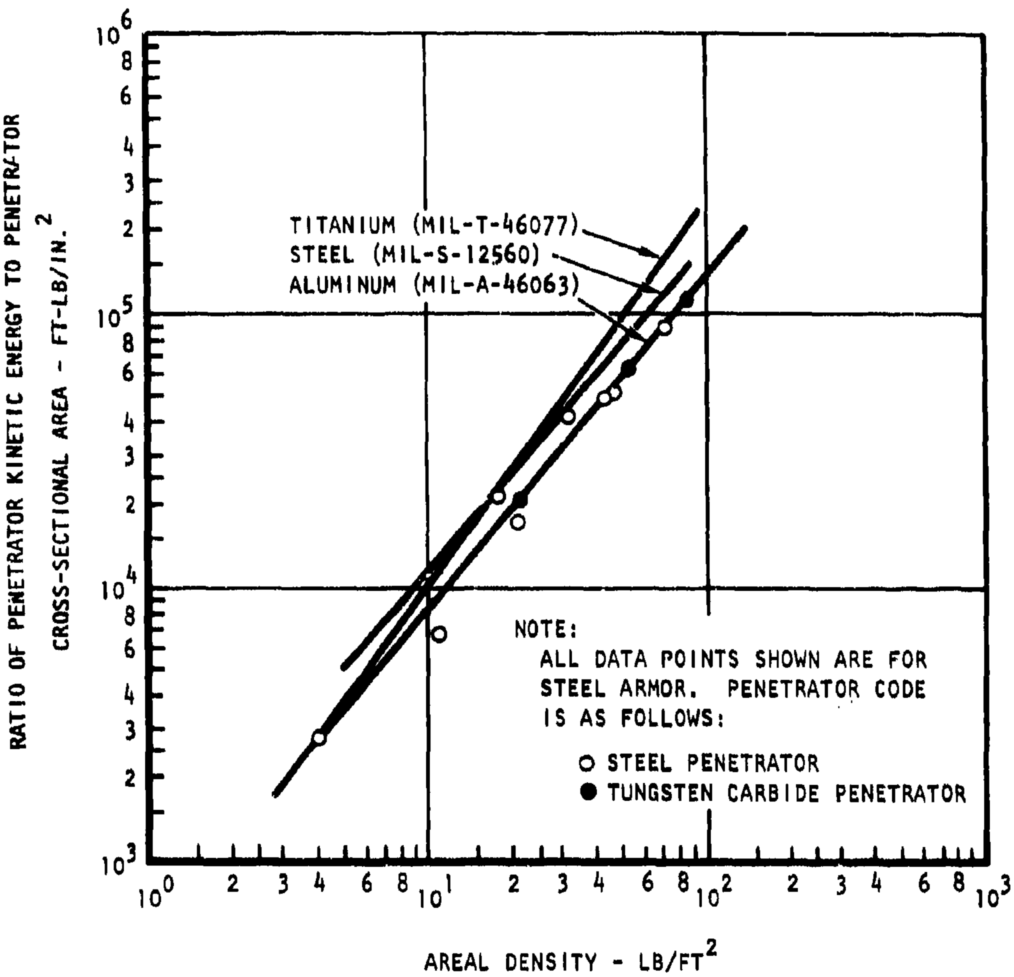

Figure 18. (C) Performance of Homogeneous Armor Materials Against Armor-Piercing Projectiles at 0 Degree Obliquity (U).

homogeneous steel armor to indicate agreement with the curve. The data points for the aluminum and titanium armor materials agree well with their curves.

(U) The curves in Figure 19 reflect terminal ballistics data. The V_{50} BL values exhibited by the armor materials at three areal density levels were determined for each of the projectiles listed in Table XI.

(U) The areal densities selected for investigation represented extreme values of the range reported, as well as the midpoint. The kinetic energy of the penetrator for each of the V_{50} BL values was then calculated. The penetrator cross-sectional area was computed from the nominal diameter of the cylindrical section. The ratio of the penetrator kinetic energy to the cross-sectional area represents the ordinate of the log-log plot in Figure 18.

(C) This particular analytical technique is not applicable to composite armor systems, since in these systems the impact kinetic energy is dissipated over an area many orders of magnitude larger than the cross-sectional area of the penetrator. This results from the fracture pattern developed in brittle materials. Therefore, the relationship shown in Figure 19 is for three familiar composite armor systems. This relationship applies only to projectiles with steel penetrators, and not to those with tungsten carbide penetrators, which have different ceramic-projectile interactions. Actual data points based on caliber .30 and .50 AP M2 projectile impacts are shown for the silicon carbide-boron armor system to illustrate agreement with the curve. It is possible that a kinetic energy and areal density plot for projectiles having tungsten carbide penetrators would show a linear relationship, with an areal density shift to higher values

TABLE XI. (C) PROJECTILE CHARACTERISTICS (U)

Projectile Nomenclature	Projectile Mass (gr)	Penetrator Mass (gr)	Penetrator Diam. (in.)	Penetrator Material
Cal .30 AP M2	166	81	0.244	Hardened steel
Cal .50 AP M2	709	400	.426	Hardened steel
14.5-mm API B32	990	633	.489	Hardened steel
14.5-mm API BS 41	994	594	.428	Tungsten carbide

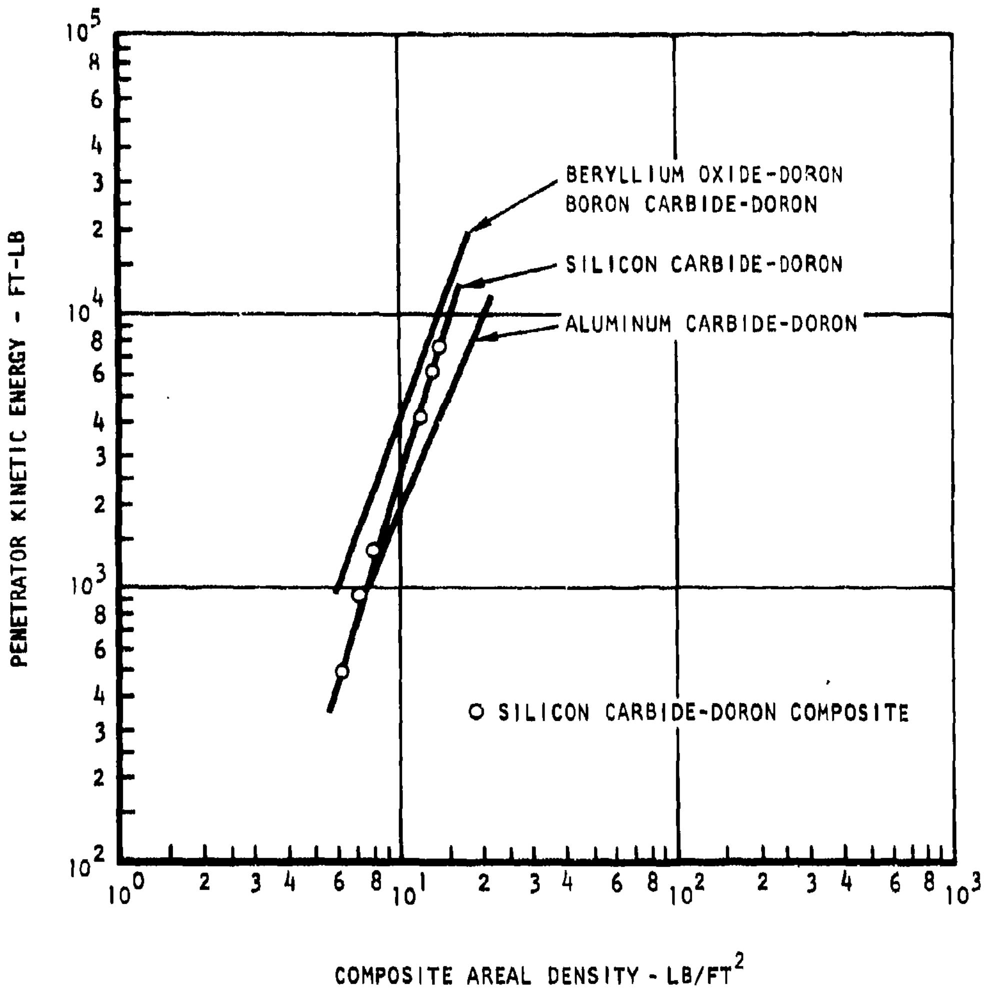

Figure 19. (C) Performance of Composite Armor Systems Against Steel-Cored, Armor-Piercing Projectiles at 0 Degree Obliquity (U).

than those of projectiles having steel penetrators. The data necessary to further explore this possibility is not currently available.

(C) The following example illustrates how the analytical treatment discussed can be applied. Let us assume that a homogeneous armor material, Armor X, exhibits sample V_{50} BL's of 950 and 1,850 fps against the caliber .30 AP M2 projectile at 4 and 10 psf, respectively. The penetrator kinetic energies for these two conditions calculated from the classic equation are 162 and 615 ft-lb. When these values are divided by the cross-sectional area of the caliber .30 AP M2 penetrator (0.0468 in.^{2}), the resultant kinetic energy and area ratios are 3,460 and 13,150 ft-lb/in.^{2}, respectively. From a linear fit of these data points, as shown in Figure 20 in log-log paper, the performance of Armor X against heavier caliber projectiles, such as the 14.5-mm API BS-41, can be estimated. At service muzzle velocity (3,280 fps), the penetrator kinetic energy and area ratio for the 14.5 mm BS-41 projectile is 98,600 ft-lb/in.^{2}. By extrapolating the curve generated from caliber .30 AP M2 ballistic data to this ratio level, it can be seen that a 40 psf areal density sample of Armor X would be expected to exhibit a V_{50} BL of 3,280 fps.

(U) It is important to realize that the ballistic performance estimated by the analytical techniques described must be verified by empirical test. There is no substitute for actual ballistic testing to define armor material capabilities.

3.6 (U) MERIT RATINGS

(U) A merit rating system has been devised to permit a quick evaluation of the comparative ballistic protection capabilities of various armor materials. The merit rating of a material relates its protection capability to the protection capability of a standard steel armor. In the case of penetrating projectiles and of those fragment-simulating projectiles larger than caliber .30 (44 grain), rolled homogeneous steel, Specification MIL-S-12560 (Ord), is used as the standard of comparison. For fragment-simulating projectiles of caliber .30 (44 grain) and smaller size, Hadfield-manganese steel, Specification MIL-A-13259, is the standard of comparison.

(U) In general, merit ratings may be based upon comparison of either of two factors - velocity (impact) or weight (areal density). A velocity merit rating is the ratio of the V_{50} protection ballistic limit (velocity) of a candidate armor material to the V_{50} protection ballistic limit of a standard steel armor having the same areal density. More recently, a

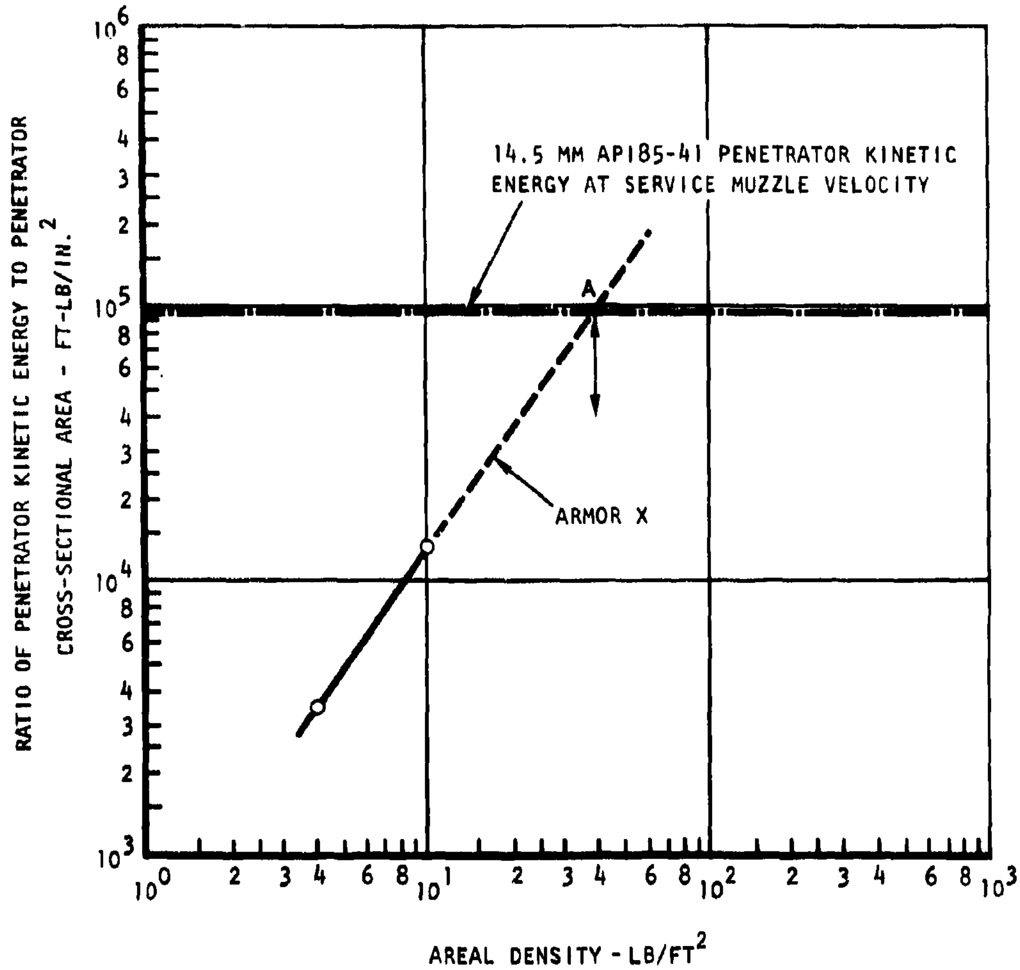

Figure 20. (C) Example Showing Projected Heavy Caliber Armor Performance From Small-Arms Ballistic Data (U).

weight merit rating has been used, in many cases, to supersede this earlier expression of comparison in terms of velocity. A weight merit rating relates the areal density of a candidate armor material to that of a standard steel armor, under conditions where each would have the same V_{50} protection ballistic limit for a specified attack. Although merit ratings could be established for any desired obliquity of projectile impact on armor, such comparisons are normally made only at 0 degrees obliquity. In terms of an equation,

$$\text{Weight Merit Rating } (MR_W) = \frac{\text{Areal Density of Standard Steel Armor}}{\text{Areal Density of Candidate Armor}} \times (100) \qquad \text{(U)}$$

(U) Merit rating comparisons are normally used only for preliminary screening of candidate armor materials for a given application. The more detailed ballistic limit data for the materials must still be used in final design evaluations.

CHAPTER 4

(C) PROJECTILE VELOCITY SLOWDOWN THROUGH LIQUID (U)

4.1 (U) INTRODUCTION

(U) This section contains classified information on the slowdown of projectiles passing through a liquid. This information supplements the unclassified data contained in section 4 of Volume I (USAAMRDL Technical Report 71-41A). The capability of aircraft fluids, particularly fuel, to slow down small-arms projectiles may be used to advantage in providing a degree of natural masking to vulnerable components or aircrewmen.

4.2 (C) FLUID MEDIUM CHARACTERISTICS (U)

(C) Slowdown of projectiles in a fluid medium is calculated by the following formula:

$$V_r = V_s e^{-\alpha R}$$

$$\alpha = \frac{Cd\ DA}{2m}$$

$$V_r = V_s e^{-CdDAR/2m}$$

V_s = Striking velocity (fps)

Cd = Drag coefficient (0.6 for projectiles and fragments)

D = Fluid density (oz/in.^{3})

A = Average presented area of projectile (in.^{2}) (side profile)

m = Weight of projectile (ounces)

R = Depth of fluid (inches)

(U) The physical characteristics of fluids most commonly associated with military aircraft are shown in Table XII.[32]

TABLE XII. (U) COMMON AIRCRAFT FLUIDS CHARACTERISTICS

Liquid	Specific Gravity	Fluid Density (oz in.^{3})
Gasoline	0.76	0.439
Hydraulic oil (MIL-H-5606)	.85	.491
JP-1	.80	.462
JP-3	.76	.439
JP-4 (0.751-0.802)	.79	.457
JP-5 (0.788-0.845)	.82	.474
Kerosene	.82	.474
Liquid Oxygen	1.14	.659
Glycerine	1.27	.734
Water	1.00	.578

(C) A nomograph, Figure 21, is provided that permits rapid determination of projectile slowdown without lengthy computations. An example is shown for slowdown of a 12.7-mm API type B-32 projectile. The specific gravity of 0.79 for JP-4 fuel with a fuel depth of 27 inches is entered into the right-hand side of the chart. From their intersection point, a horizontal line is drawn to intersect the A/m value for the 12.7 mm API projectile. This intersection point is used to follow the curved line to the reference line. This provides the intersection point for following the diagonal reference lines until it intersects the projectile striking velocity (V_S) value vertical line. Constructing a line horizontally to the left provides the intersection with the remaining velocity scale (V_r) on the left-hand side of the chart. For this example, the striking velocity of 2,000 feet per second has been reduced to 240 feet per second by passing through 27 inches of JP-4 fuel.

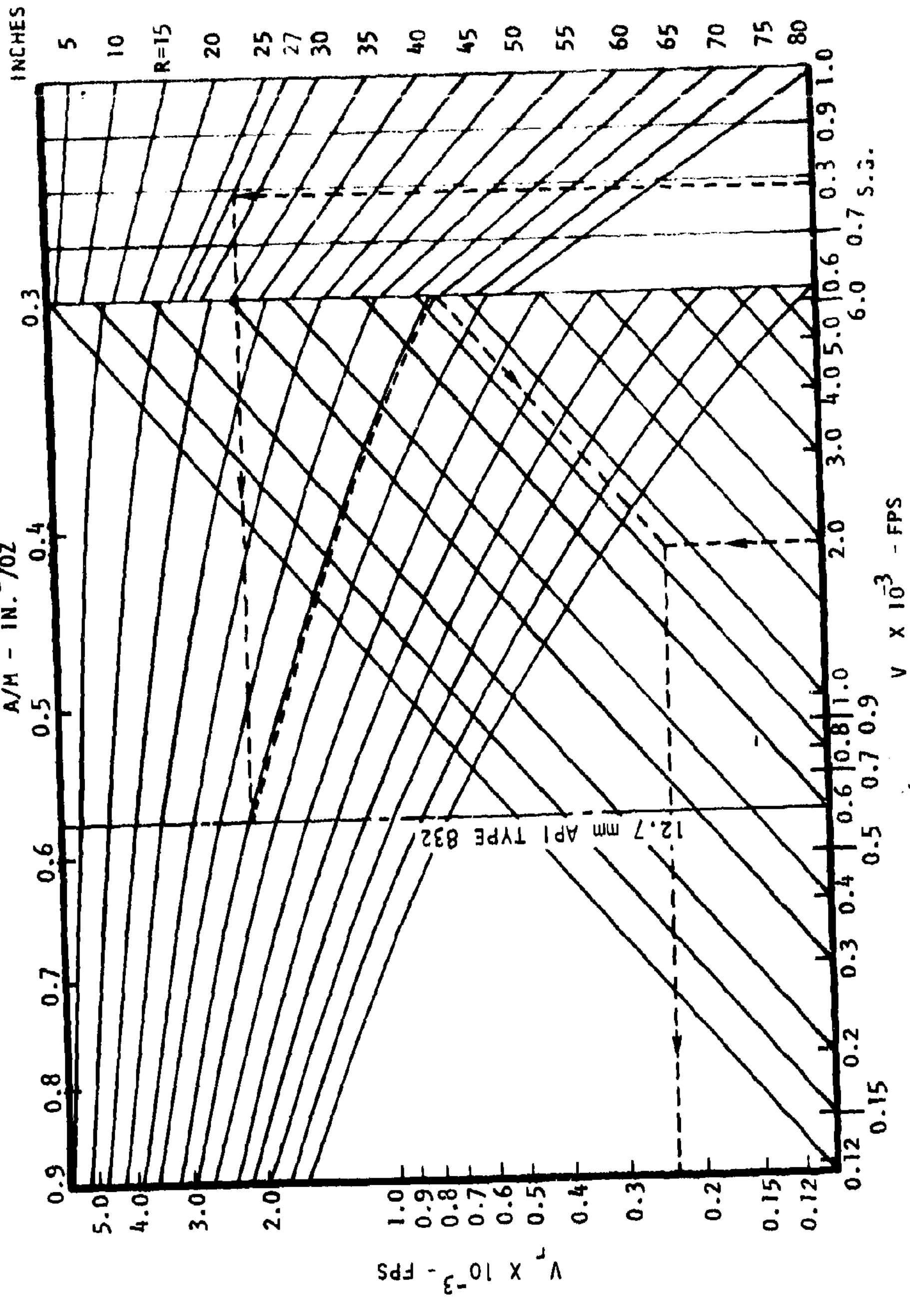

Figure 21. (C) Residual Velocity V_r of Penetrator Through a Liquid (U).

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13. ABSTRACT

(U) An extensive literature and information search was conducted to identify military aircraft small-arms protection enhancement techniques developed during the past 10 years. This data was analyzed and used to develop a comprehensive survivability design guide for incorporation of ballistic protection features in U.S. Army aircraft. This document contains classified information that supplements the information contained in the unclassified volume I (USAAMRDL Technical Report 71-41A).

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Aircraft Survivability						
Survivability Enhancement Techniques						
Small-Arms Ballistic Protection						
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